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FACULTY OF ENGINEERING AND THE ENVIRONMENT

INSTITUTE OF SOUND AND VIBRATION RESEARCH

Acoustic Characterisation of Cinema Screens

by

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Proyecto

Tema y Título:	Acoustic Characterisation of Cinema Screens
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Abstract

As a consequence of cinema screens being placed in front of screen-speakers, a reduction in sound quality has been noticed. Cinema screens not only let the sound go through them, but also absorb a small amount of it and reflect the sound which impacts on the screen to the back, coming forward again in case it impacts on the loudspeaker. This backwards reflection in addition to the signal coming from the loudspeaker can lead to constructive or destructive interference at certain frequencies which usually results in comb filtering.

In this project, this effect has been studied through researching amongst various data sheet provided by different manufacturers, acoustical measurements completed in the large anechoic chamber of the ISVR and some theoretical models developed with MatLab software.

If results obtained with MatLab are accurate enough in comparison to the real measurements taken in the anechoic chamber this would lead to a good way to predict which would be the attenuation added to the system at each frequency, given that not all manufacturers provide an attenuation curve, but only an average attenuation. This average attenuation might be useless as sound waves have different wavelengths and its propagation through partitions varies. In fact, sound is composed by high and low frequencies, where high frequencies are characterised by a small wavelength which is usually easier to attenuate than low frequencies that characterised by bigger wavelengths.

Furthermore, this information would be of great value to both screen manufacturers, who could offer a much more precise data in their data sheets; and customers, who would have a great amount of information to their disposal before purchasing and installing anything in their cinemas, being able to know by themselves which screen or loudspeaker should be best to meet their expectative.

Resumen

La aparición de la digitalización de las bandas sonoras para las películas hace posible la mejora en la calidad de sonido de los cines. Sin embargo, un aspecto a tener en cuenta en esta calidad del sonido es la transmisión de éste a través de la pantalla, ya que normalmente tras ella se encuentran situados los altavoces. Las propiedades acústicas varían dependiendo del tipo de pantalla que se utilice, además de haber poca información a la que acceder para poder valorar su comportamiento.

A lo largo de este proyecto, se analizan tres muestras de pantallas distintas donadas por distintos fabricantes para poder llegar a la conclusión de dependiendo del tipo de pantalla cuál es la distancia óptima a la que localizar la pantalla respecto al altavoz y con qué inclinación. Dicho análisis se realizó en la cámara anecoica del ISVR (University of Southampton) mediante la construcción de un marco de madera de 2x2 m en el que tensar las pantallas de cine, y un altavoz cuyo comportamiento sea el más similar al de los altavoces de pantalla reales. Los datos se captaron mediante cuatro micrófonos colocados en posiciones distintas y conectados al software Pulse de Brüel & Kjær, a través del cual se obtuvieron las respuestas en frecuencia del altavoz sin pantalla y con ella a diferentes distancias del altavoz. Posteriormente, los datos se analizaron con MatLab donde se calculó la atenuación, el factor de transmisión de la presión (PTF) y el análisis cepstrum. Finalmente, se realizó un modelo teórico del comportamiento de las pantallas perforadas basado en las placas perforadas utilizadas para atenuar el sonido entre distintas habitaciones.

Como conclusión se llegó a que las pantallas curvadas son acústicamente más transparentes que las pantallas perforadas que a partir de 6 kHz son más acústicamente opacas. En las pantallas perforadas la atenuación depende del número de perforaciones por unidad de área y el diámetro de éstas. Dicha atenuación se reducirá si se reduce el diámetro de las perforaciones de la pantalla, o si se incrementa la cantidad de perforaciones. Acerca del efecto filtro peine, para obtener la mínima amplitud de éste la pantalla se deberá situar a una distancia entre 15 y 30 cm del altavoz, encontrando a la distancia de 30 cm que la última reflexión analizada a través de Cepstrum llega 5 ms más tarde que la señal directa, por lo cual no debería dañar el sonido ni la claridad del habla.

Acknowledgements

I would like to be grateful to everyone involved in making this project possible.

First of all, the biggest “thank you” is for my parents. You can’t imagine how grateful I am for your support provided all through my degree, both in Spain and in the UK. This would have never come true without you. I am very happy to have you beside me in any decision that I made. I love you.

I would also like to thank you my supervisor Dr. Keith Holland, who gave me the opportunity to develop this project in such an unknown area and for your help with MatLab, had not it been for you I would still be stuck in line 1. Thank you to Philip Newell, for your countless number of emails giving your opinion on how to do the measurements and explanations.

My high school teachers deserve a big recognition. If it wasn’t for the education you provided to me, reaching this point would have been impossible. Thank you for being such enthusiastic teachers. My lecturers in Spain also deserve being listed here. I enormously appreciate all the knowledge you have transmitted to us. Many of you are a great example to follow, and even though some of your exams were evil, the effort to pass them was worthwhile to get here.

A special thank you to my friend Marta. You have been of great help and encouragement throughout this year; I really appreciate having met you and became such good friends. Elvira, your hugs are the best ones and I will never forget any of them, as well as none of these four last years of Uni.

Thank you, to the rest of my friends. You know who you are, there is no need to name anyone. If at any moment you have supported me and believed that I could do it this is for you. You are a great pillar in my life.

Jana.

Contents

Total number of words: 6715

1. Introduction

Cinema screens are placed in front of screen-speakers. Ideally, these screens should not reduce sound quality in any way, in order to ensure the audience may listen to the audio of the film with the cleanest sound as possible. T his characteristic is known as acoustical transparency. However, screens are not completely transparent and manufacturers do not reveal very precise information concerning sound transmission through them.

As very little literature is available to explain the performance of the sound transmission through cinema screens, measurements were taken in order to make it possible to explain this phenomenon. There are various types of cinema screens, e.g. curved, perforated or non-perforated screens, and the sound performance varies in each of them. These screens can be mounted loosely or in a frame which ensures they are taut.

In cinemas, screen speakers are located behind the screen, resulting to be impossible to be seen by the audience. Though these screens are meant to be acoustically transparent, there is always a very small percentage of sound energy which is either absorbed or reflected backwards. This backwards reflection is usually lost, so detail is also lost at that frequency. Where energy is absorbed, detail is obscured.[1]

By combining a number of theoretical models that already exist based on sound transmission through partitions, it will be possible to predict the behaviour of the cinema screens.

Plus, any data related to acoustical transparency found in data sheets do not usually reveal how this factor was measured (distance between the loudspeaker and the screen) or how it should be mounted to avoid comb filtering.

2. Researched information

As far as it is known, cinema screens insert attenuation within the sound. This information related to attenuation is not always found in data sheets, or an overall attenuation value is given. However, it must be borne in mind that this attenuation is frequency dependant due to the perforation size and density that influence the sound transmission through the screen.

Moreover, the second problem is comb filtering. When a sound wave travels from the loudspeaker towards the audience it needs to go through the screen. The first problem which appears is that some waves are reflected backwards, impacting on the loudspeaker and going forward again; mirror effect. Depending on its phase it could lead to constructive or destructive interference at some frequencies, which is known as comb filtering

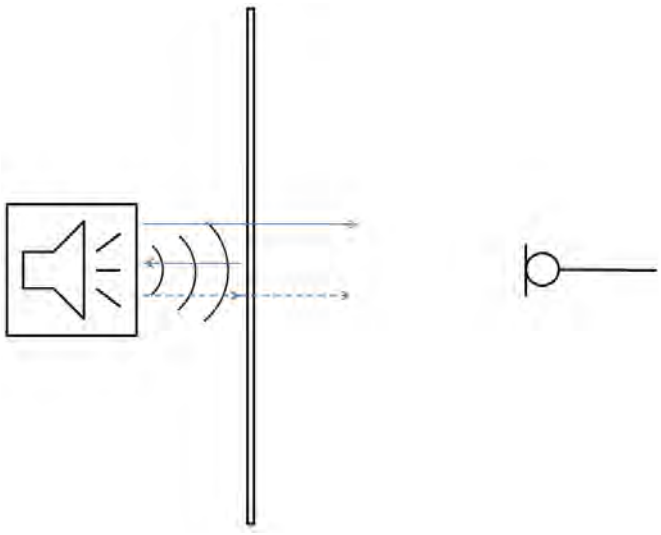

Fig. 2.1: How comb filtering occurs

Throughout this project, measurements are going to be taken with three different screens donated by various manufacturers.

Screen Excellence provided a screen sample of **Enlightor 4K**. This screen is woven and praised to be one of their best ones as its acoustic transparency is regarded as good. Treble at 20 kHz was 2.5 dB down than at 2 kHz. Plus, the screen gain is 0.98,[2] which is considered to be very acceptable, as best screens are those which its gain is close to 0, meaning that the light is reflected equally in every direction and audience in every position will see the image projected with the same brightness.

Published Gain	Max SPL Loss dB	Published Gain	Measured % Diff.	On Axis Gain	Off Axis Gain	On Axis Max. xy	On Axis Avg. xy	Off Axis Max. xy	Off Axis Avg. xy
Enlightor 4K*	2.5	0.98	-14%	0.84	0.83	0.004	0.002	0.005	0.002

Fig. 2.2: Characteristics for Enlightor 4K, by Screen Excellence.

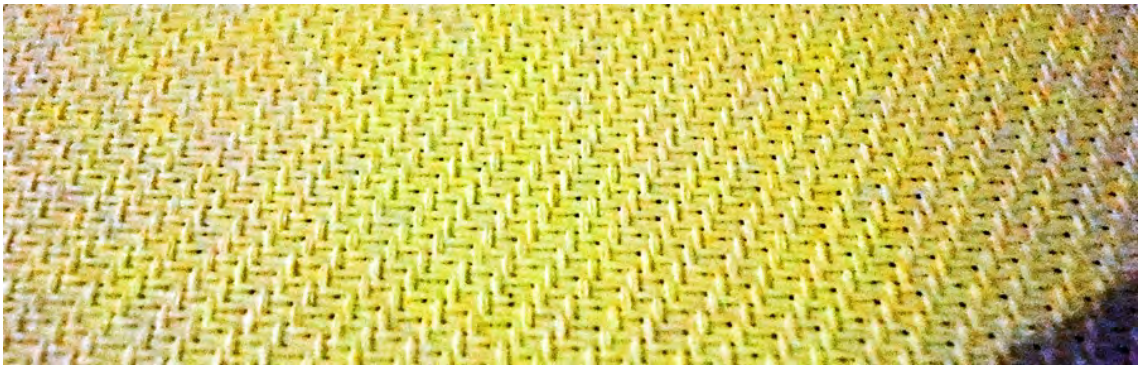

Fig. 2.3: Sample of the screen Enlightor 4K, picture taken in the Anechoic Chamber (Feb 6th, 2013)

The second screen sample which was used in this project is **Matt Plus Miniperforated**, manufactured by Harkness Screens[3]. This sheet is perforated, as its own name suggests. It is approximately 3 years old, but has been barely used, so it is surprisingly clean and results should be similar to the ones obtained with a new screen sheet. Matt Plus is a white miniperforated screen ($\varnothing$ = 0.5 mm) with a 0.3 mm thickness and a maximum gain of 1.0 which decreases in function of the viewing angle, as it can be seen in Fig. 2.4. It is usually used in screening rooms or small cinemas where the front row of seats is close to the screen sheet and standard perforation holes ($\varnothing$ = 1.2 mm) can be seen.

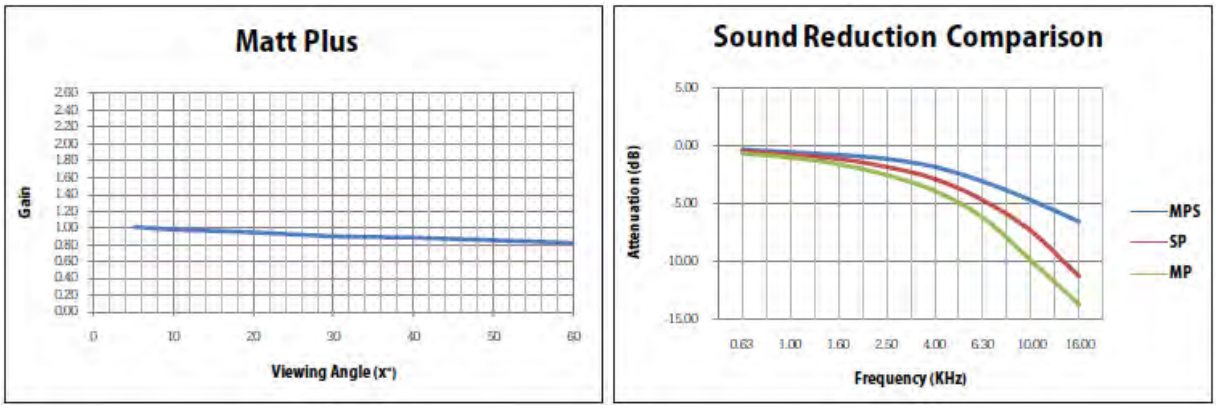

Fig. 2.4: Matt Plus gain (left) and attenuation between the different types of Matt Plus screens which are available in the market (Standard-Perforated, Mini-Perforated or Mini-Perf Super) 4 (right).

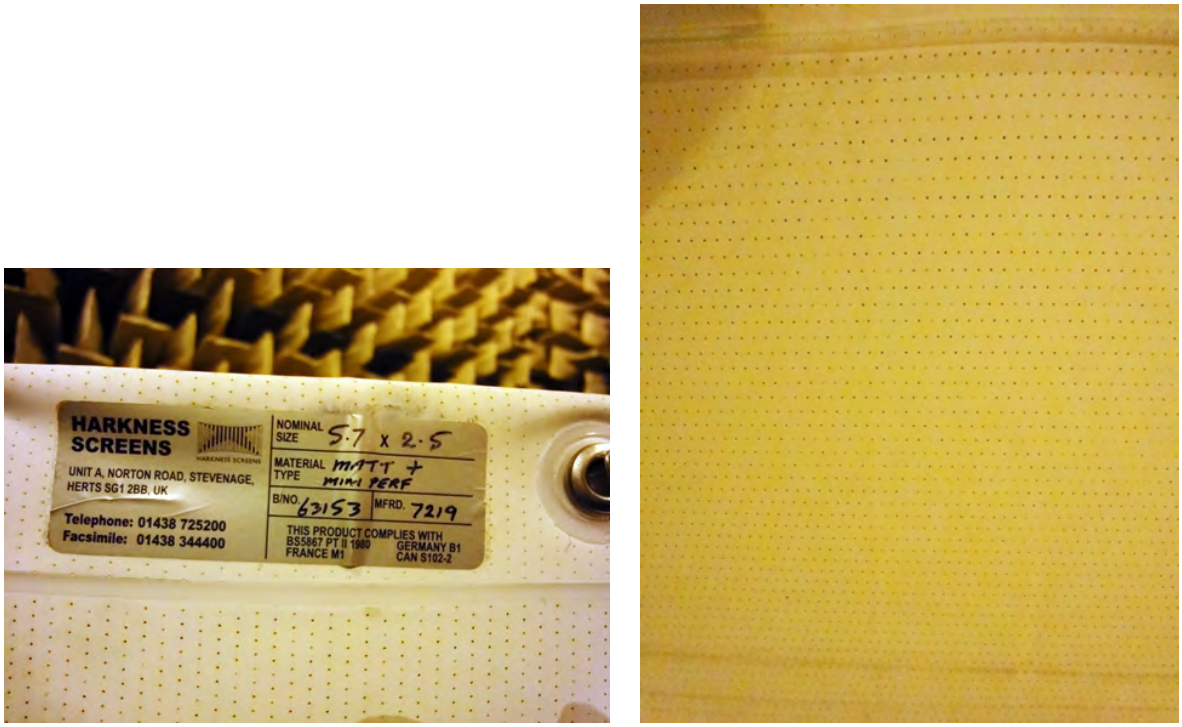

Fig. 2.5: Matt Plus MiniPerforated screen by Harkness Screens, pictures taken in the Anechoic Chamber (Feb 7th, 2013)

As it can be seen in Fig. 2.4 (right), attenuation for Matt Plus MiniPerforated at 5 kHz is -5dB and at 10 kHz is -10 dB, which is a large amount to keep in mind as these frequencies are largely found in film audio.

The last screen sheet used was **ClearPix 2 White 1.0** by Screen Research. ClearPix 2 White 1.0 is also a woven screen. Datasheet praises this screen's material is certified by both THX and ISF guarantying excellent video and audio performance and eliminating the comb filtering found in perforated screens. It has

a 1.0 gain and an acoustic transparency measured at 1m from the loudspeaker with the screen in between of 1.5 dB loss for frequencies between 10 kHz and 20 kHz. Its structure is non-geometrical aiming to let sound pass through it with minimal attenuation.[5]

Material Type

Material Type	Flexible Front Projection
Gain	1.0
Half Gain	N/A
Viewing Angle	160°
Minimum Recommended Width for 4K	2.0m
Minimum Throw Distance	N/A
Video Transparency	3%
Video Transparency (incl. BB Layer)	0.5%
Acoustic Transparency	-1.5dB (10kHz – 20kHz)
Acoustic Transparency (incl. BB Layer)	-2.25dB (10kHz – 20kHz)
Ambient Light Resistance	3/10
Lay Flat Quality	Excellent
Flame Resistance	Yes

Fig. 2.6: ClearPix 2 White 1.0 characteristics, by Screen Research

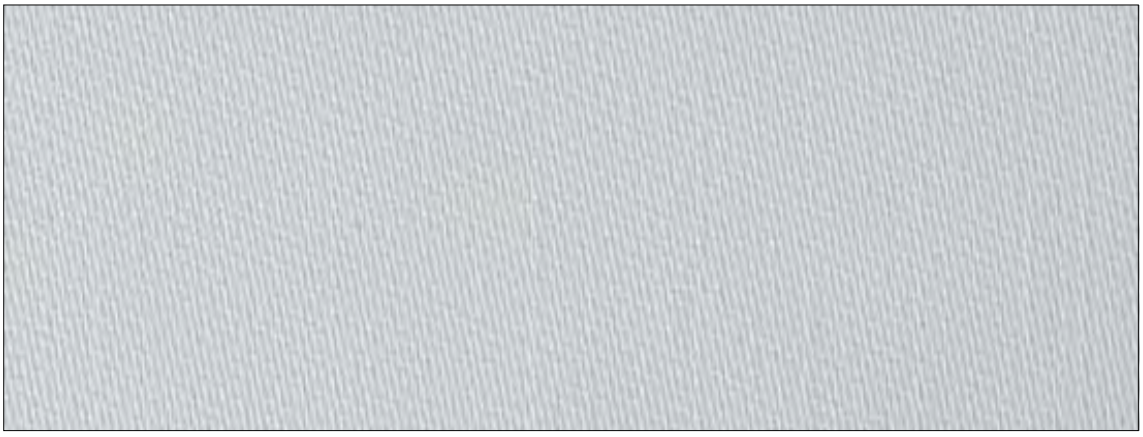

Fig. 2.7: ClearPix 2 White 1.0, picture obtained from datasheet.[5]

3. Measurements

3.1. Layout

Measurements were taken in the large anechoic chamber of the ISVR. This chamber is characterised by over 8,000 non-flammable glass-fibre cored wedges placed on the walls, floor and ceiling, leading to free-field conditions at frequencies above 80 Hz. The volume of the chamber without the wedges is 611 m^3, and its usable volume between the wedges is 295 m^3.[6] It was decided to leave the grid of removable floor panels as a feature of this specific anechoic chamber is that they do not interfere with its anechoic nature. This way, measurements will be safer and falls over the edges of the grid will be avoided.

Before starting the measurement process, it was necessary to make sure all the screens were available. As it has previously been said, three different screen samples were received: **Enlightor 4K**, **Matt Plus MiniPerforated** and **ClearPix 2 White 1.0**. To make possible the process of measuring, it was constructed a frame in where to place the screen samples and apply a tension to simulate the conditions found in a real cinema. It is very important to have the screen samples well tensioned for a good result. Finally, it was decided to create a 2x2 m^2 frame, as shown in Fig. 3.1, and staple the screens to it, instead of using the gripfix profile and the spatula provided by Screen Excellence, as Fig. 3.2 shows. These dimensions were decided according to the limited dimensions (2x2 m^2) of one of the screen samples received.

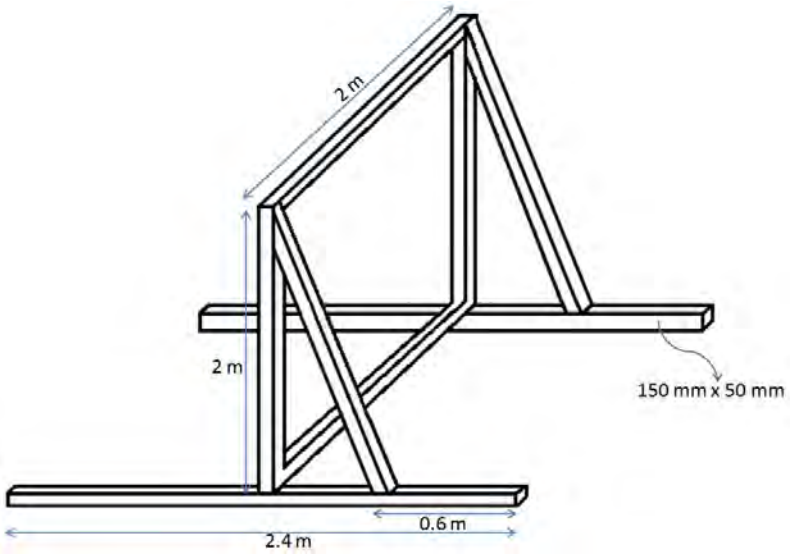

Fig. 3.1: Frame sketch

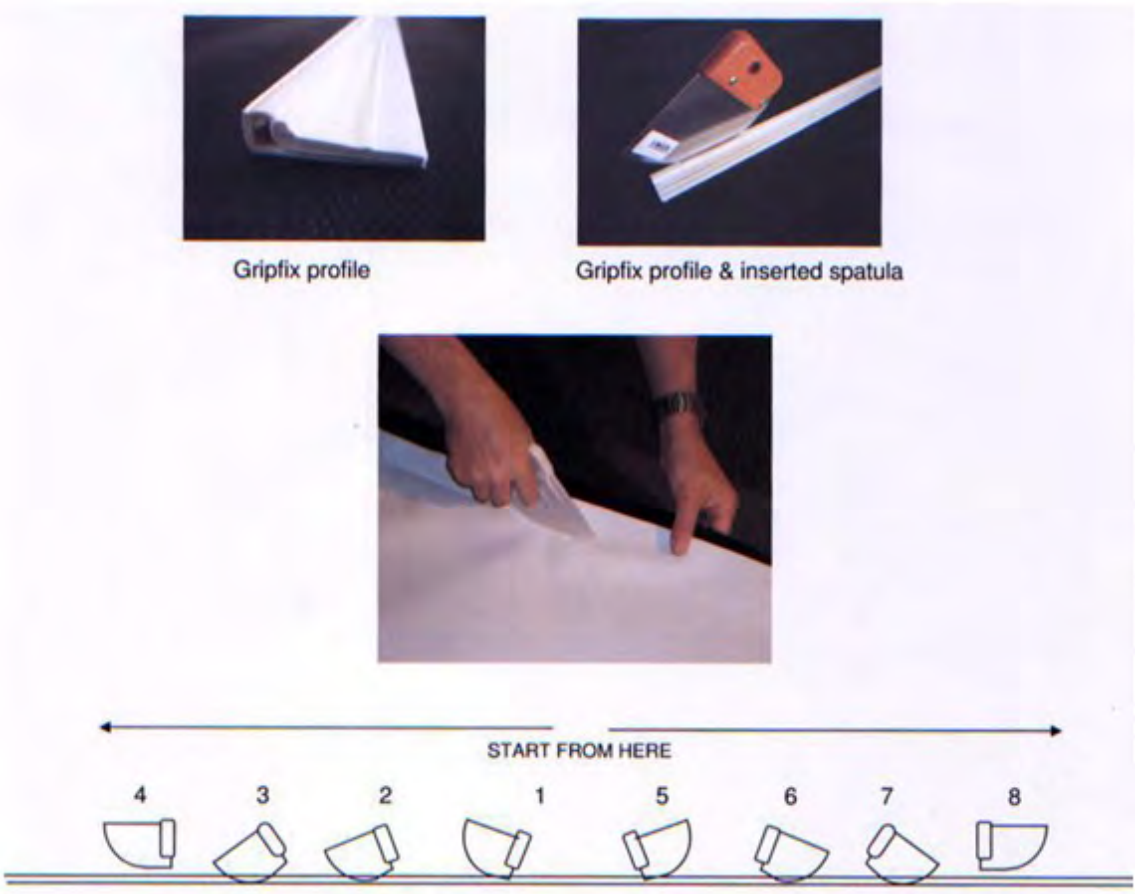

Fig. 3.2: Gripfix profile and spatula, by Screen Excellence[7]

Then, 4 microphones were located at a distance of 3 meters from the speaker at different angles: 0, 15, 30 and 45 degrees and set up at 1.20 m height. This was done so to have an idea of how audience would perceive the sound at different positions in a cinema, as not everyone sits on the sweet spot.

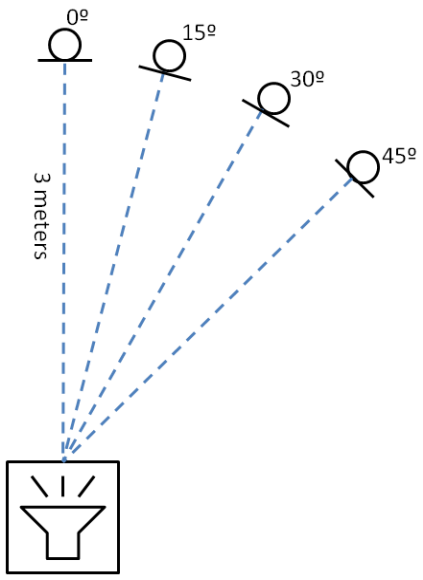

Fig. 3.3: Microphones location

The pre-amplified microphones used were by Brüel & Kjær, model 4189-L-001, which is pre-polarised. Its sensitivity is 50mV/Pa and the frequency range goes from 6.3 Hz to 20 kHz[8]. The range of frequencies that this project will evaluate is from 100 Hz to 16 kHz, as the voice speech of a typical adult male has a fundamental frequency from 85 to 180 Hz and that of a typical adult female from 165 to 255 Hz.[9]. Then, the rest of the frequencies are also important as films are composed by dialogues, random noises and music sound track. Music will be the feature with a wider range of frequencies.

Fig. 3.4: Microphone 4189-L-001 by Brüel & Kjær

The loudspeaker chosen was ElectroVoice T251 as behaves similarly to the real screen loudspeakers in cinemas. It presents a flat frequency response, especially at high frequencies, as it can be seen in Fig. 3.6. It was located at 1 m high so the centre of the loudspeaker was at the centre of the screen. Then, a pink noise signal was used as an input, as the spectral power of this kind of signal is the same at all frequencies. In pink noise each octave carries an equal amount of noise power and if amplified with a loudspeaker in a room we can calculate the

acoustical performance of the loudspeaker, the room acoustics parameters, etc. It is usually generated between 20 Hz and 20 kHz, which is the range of frequencies the human can listen to.

Fig. 3.5: ElectroVoice T251

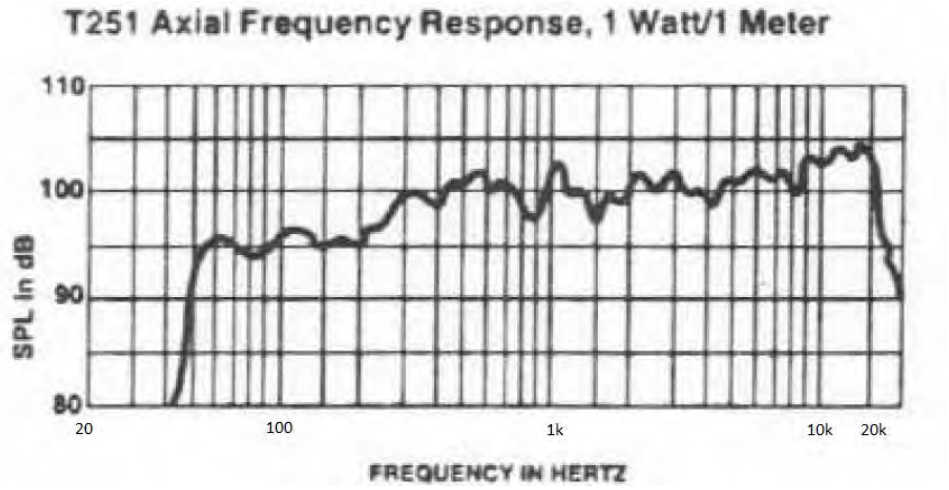

Fig. 3.6: Frequency Response of the loudspeaker EV T251, by ElectroVoice

As it can be seen in Fig. 3.7, for reasons unknown the loudspeaker presents a poor response on-axis at 1.7 kHz, which off-axis will worsen. It should be taken into account when going through results because this poor response may alter conclusions, although as results are a comparison between results with screen and with no screen, the absolute response of the loudspeaker will not be determining.

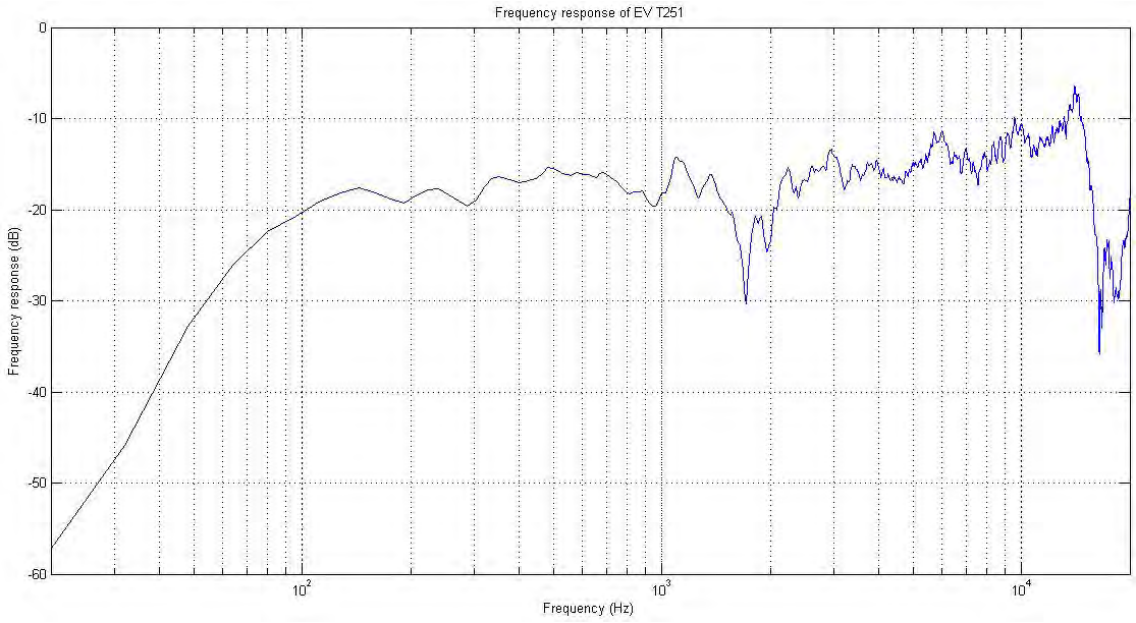

Fig. 3.7: Frequency Response of the loudspeaker EV T251, measured in the anechoic chamber

Screen samples were located at distances from the speaker of 2 cm, 7 cm, 15 cm, 30 cm, 45 cm and 60 cm, and then with the screen sample angled 10 and 25 degrees in relation to the speaker. In Fig. 3.8, Fig. 3.9 and Fig. 3.10, it can be seen a sketch of the way in which it was angled and real photographs of the set up itself.

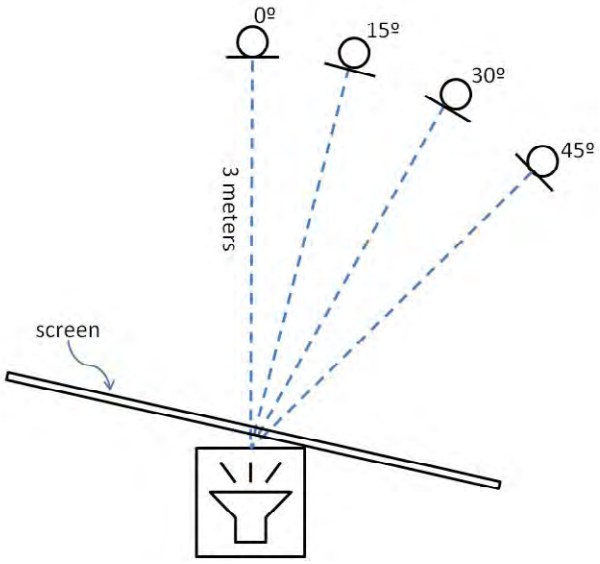

Fig. 3.8: Microphones location with screen angled

Results commented throughout this report will be related to the on-axis microphone position. In case the reader would like to go through the different results for the 15º, 30º and 45º microphone positions they can be found in the appendices, at the end of the report.

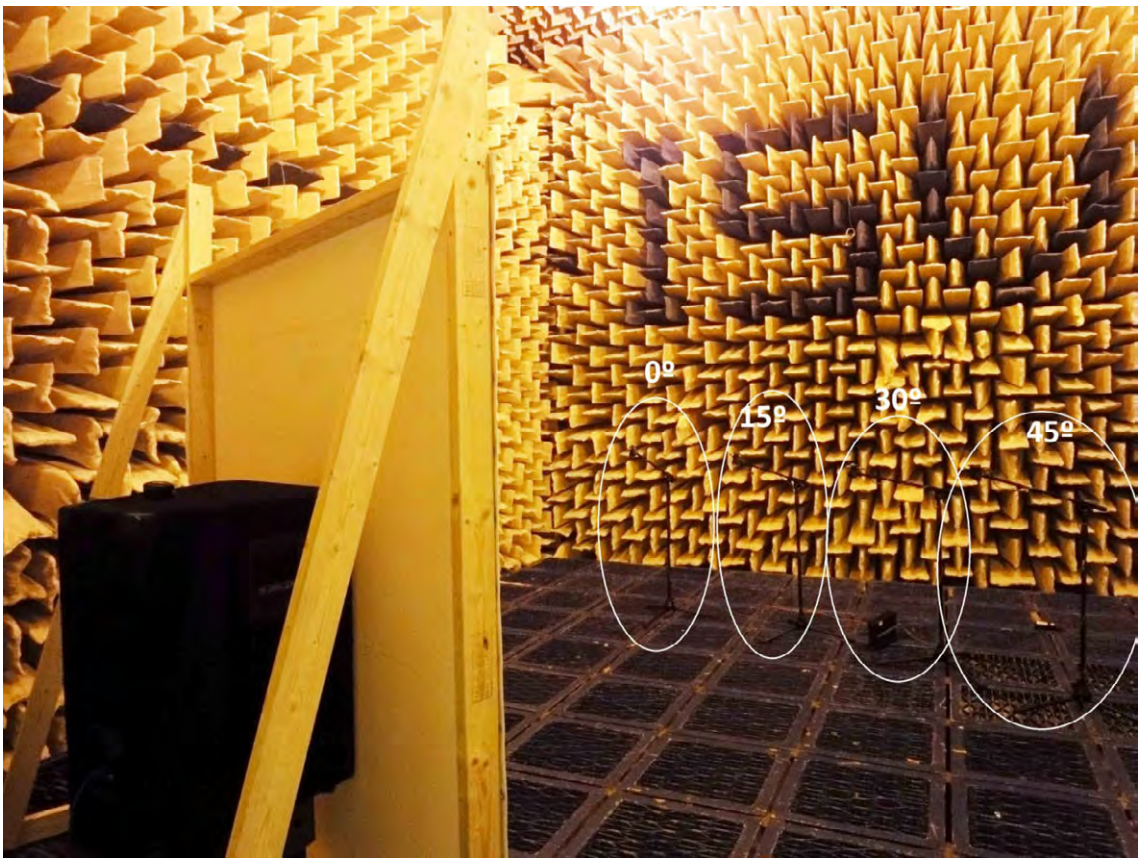

Fig. 3.9: View of the loudspeaker, angled screen and microphones at different positions

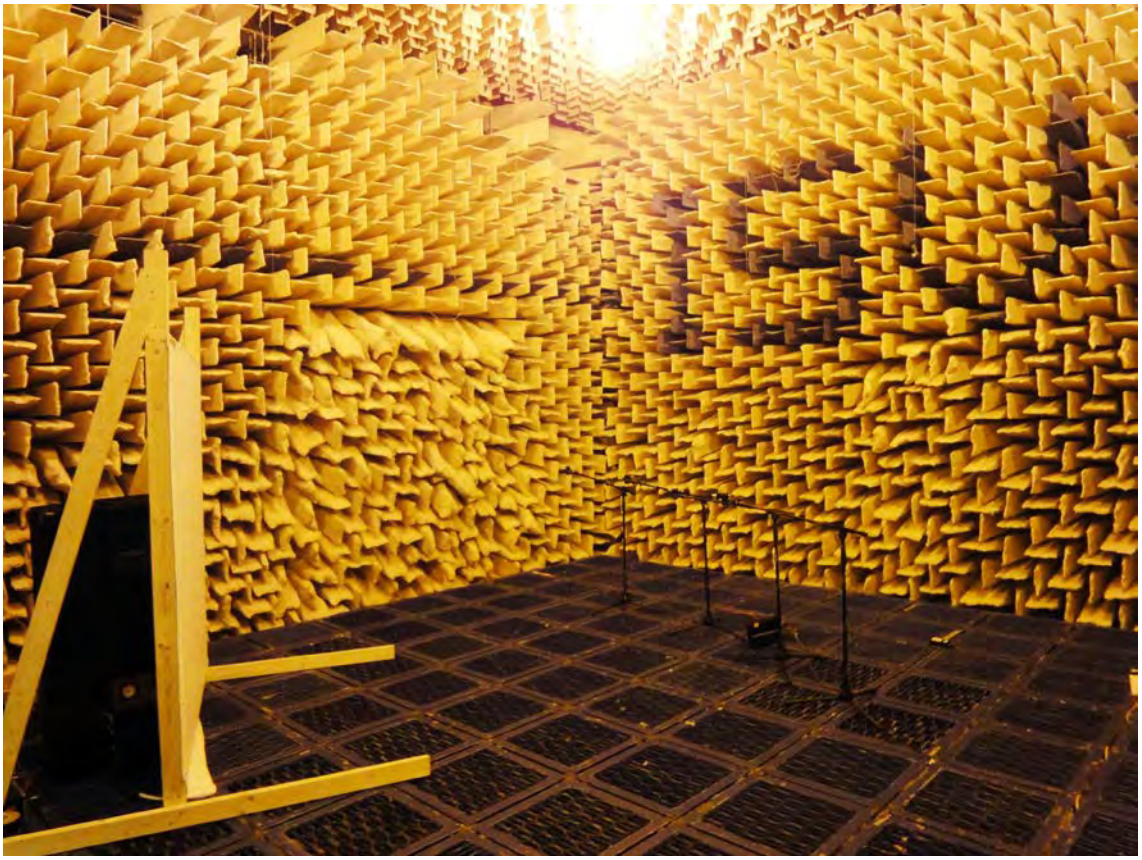

Fig. 3.10: Overall view of the anechoic chamber with the loudspeaker, angled screen and microphones at 0, 15, 30 and 45 degrees

From figures Fig. 3.11 to Fig. 3.15 it can be seen the layout of the loudspeaker with respects to the screen in every different distance and angle it was located to take the measurements.

Fig. 3.11: Loudspeaker located at a distance of 2 cm (left) and 7 cm (right) from the screen

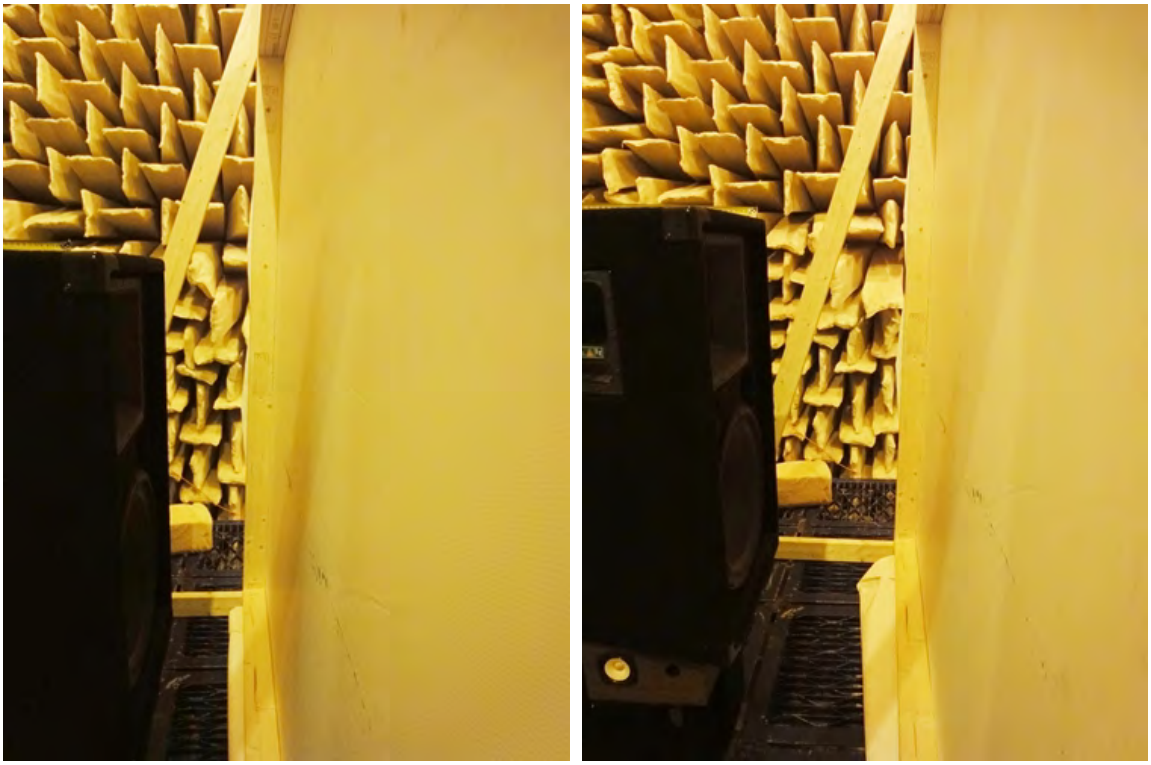

Fig. 3.12: Loudspeaker located at a distance of 15 cm (left) and 30 cm (right) from the screen

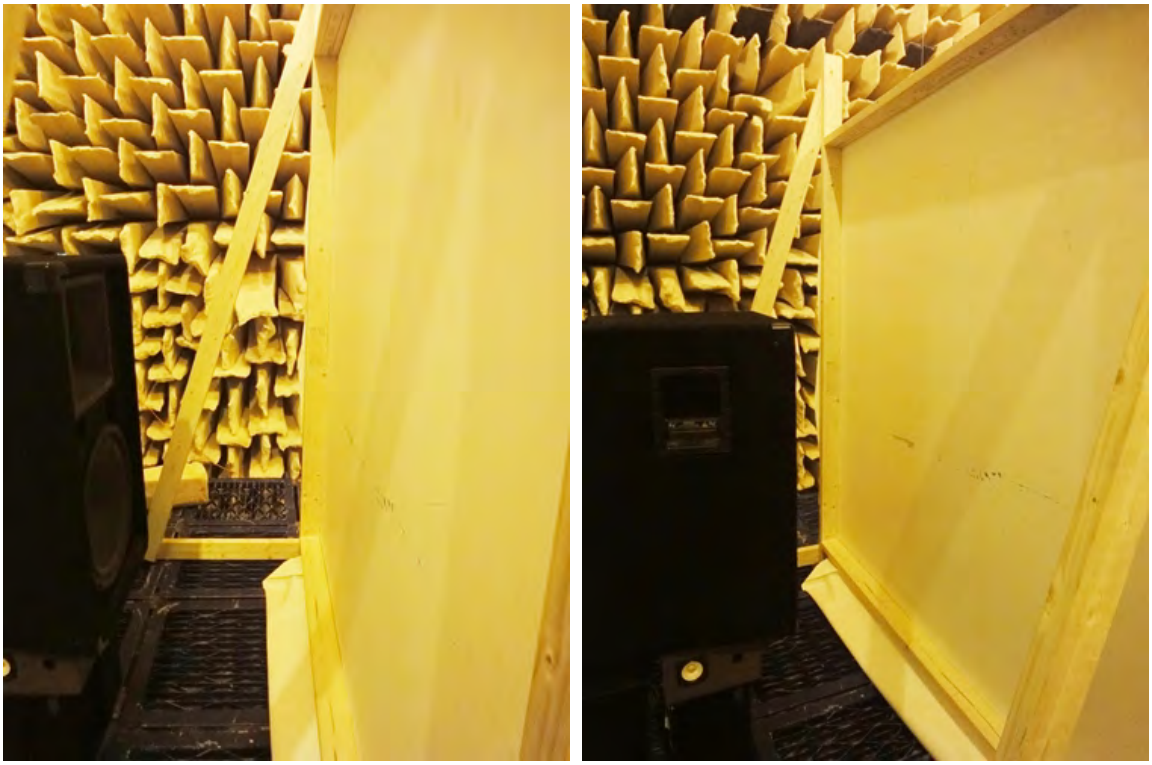

Fig. 3.13: Loudspeaker located at a distance of 45 cm (left) and 60 cm (right) from the screen

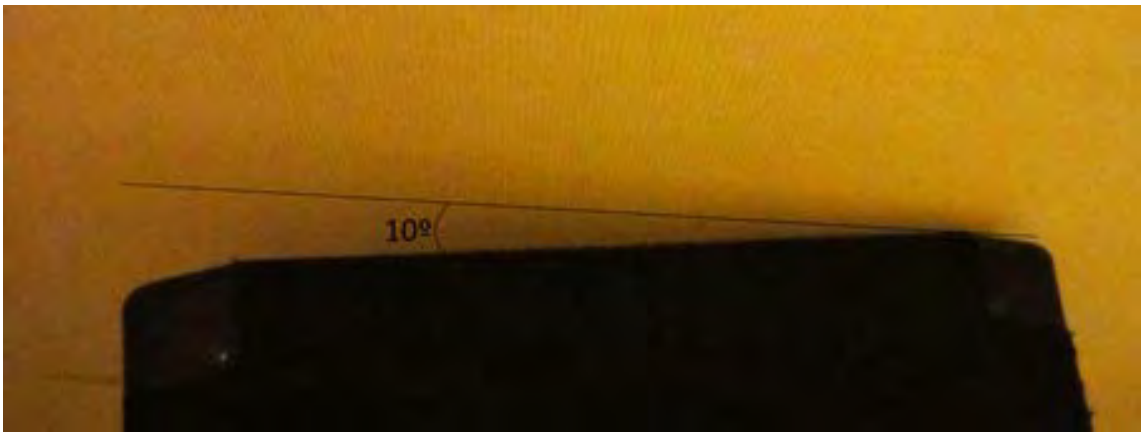

Fig. 3.14: Screen angled 10 degrees with respect to the loudspeaker

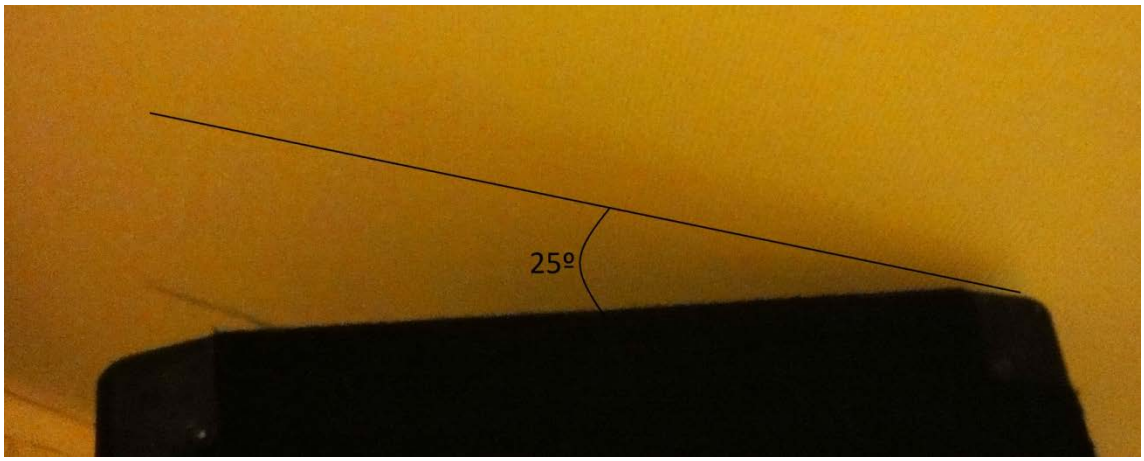

Fig. 3.15: Screen angled 25 degrees with respect to the loudspeaker

By means of using Pulse software by Brüel & Kjær, data were collected and stored. Afterwards, using MatLab, different calculations on collected data were carried out to ensure that specified screen features stated by manufacturers were actually worked in practice.

3.2. Pressure Reflected and Transmitted Factor

As it was mentioned in the Interim Report, pressure reflection factor (PRF) and pressure transmitted factor (PTF) are used as a method to have a brief knowledge of how the screens are going to behave in what is related to sound absorption, reflection and transmission. They way to calculate both factors is as follows.

The pressure reflection factor (PRF) at each frequency is the ratio of the reflected sound pressure to the incident sound pressure.

$$PRF = \frac{p_{reflected}}{p_{incident}} \qquad 0 < PRF < 1 \tag{3.1}$$

If PRF = 1, indicates a completely reflective surface.

If PRF = 0, indicates a completely non-reflective surface.

The pressure transmitted factor (PTF), also known as sound pressure transmitted through the screen, is the ratio of the transmitted sound pressure to the incident sound pressure.

$$PTF = \frac{p_{transmitted}}{p_{incident}} \qquad 0 < PTF < 1 \tag{3.2}$$

If PTF = 1, indicates a completely acoustically transparent screen.

If PTF = 0, indicates a completely acoustically opaque screen.

Because of the way measurements were taken, it is only possible to calculate this latter factor. In the following figures the conclusion reached according to the PTF factor is that the best screen is the Enlightor 4K, as the PTF remains in higher values along more frequencies at different distances than the other screens.

PTF>0.95 for most of the low and middle frequencies, and 0.5<PTF<0.95 at all distances below 8 kHz. For frequencies above 8 kHz, PTF decreases a bit, although it is still a good value, as the most important frequencies covers up to 12 kHz. All these figures are related to on-axis microphone.

PTF for screen Enlightor 4K

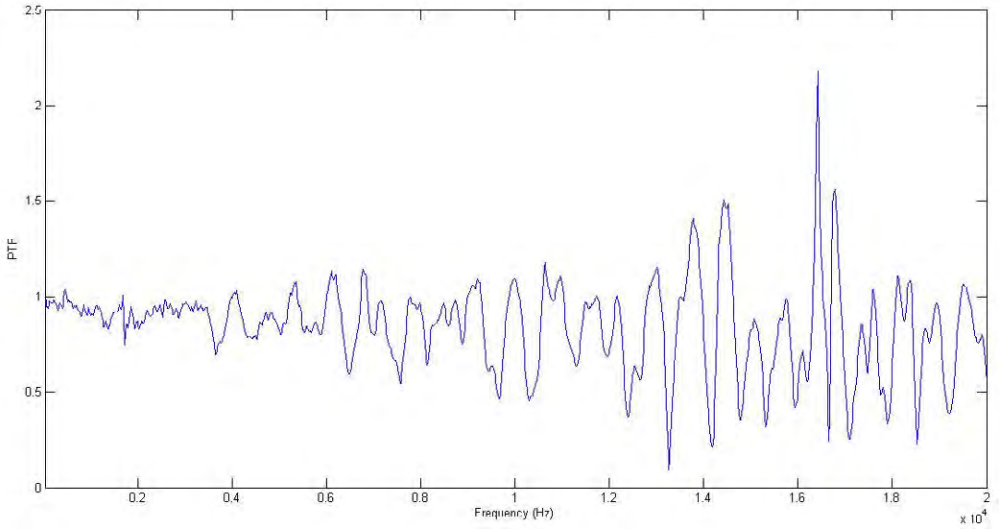

Fig. 3.16: PTF for screen Enlightor 4K at a distance of 2cm

At a distance of 2 cm, the frequencies found affected by PTF<0.4 were from 8 kHz and above and from 6.5 kHz for PTF<0.6

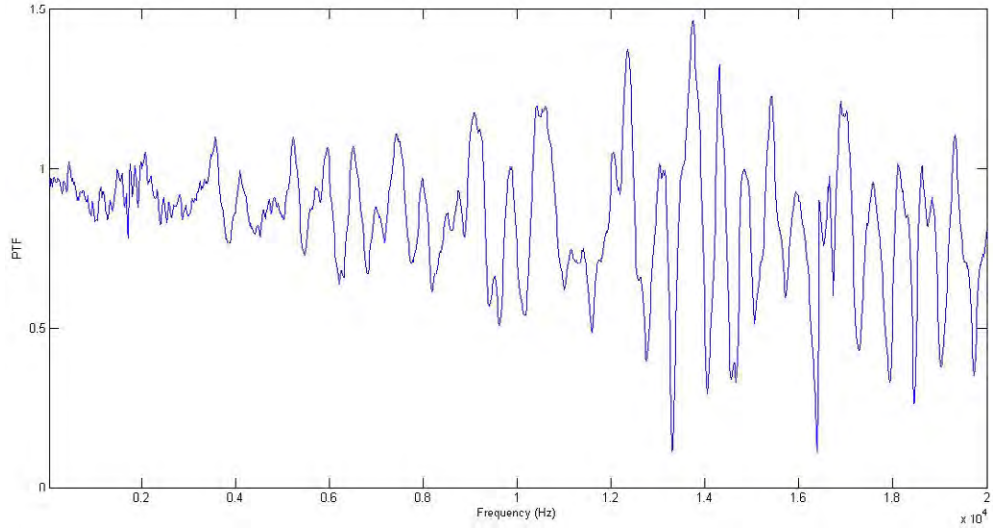

Fig. 3.17: PTF for screen Enlightor 4K at a distance of 7cm

At a distance of 7 cm, the frequencies affected by PTF<0.5 were from 11.5 kHz onwards.

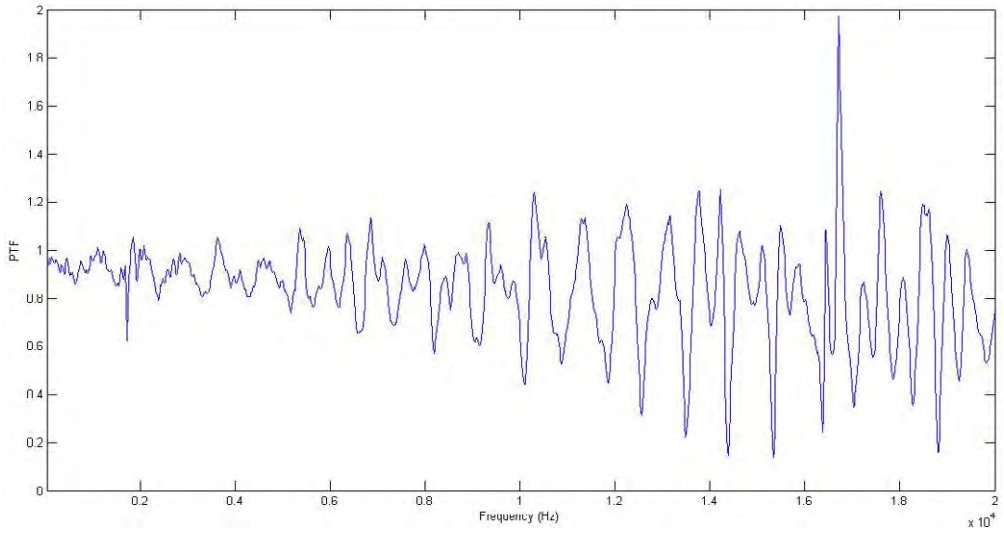

Fig. 3.18: PTF for screen Enlightor 4K at a distance of 15cm

At a distance of 15 cm, the frequencies with a PTF<0.5 started at 12.5 kHz, and PTF<0.6 started at 8 kHz.

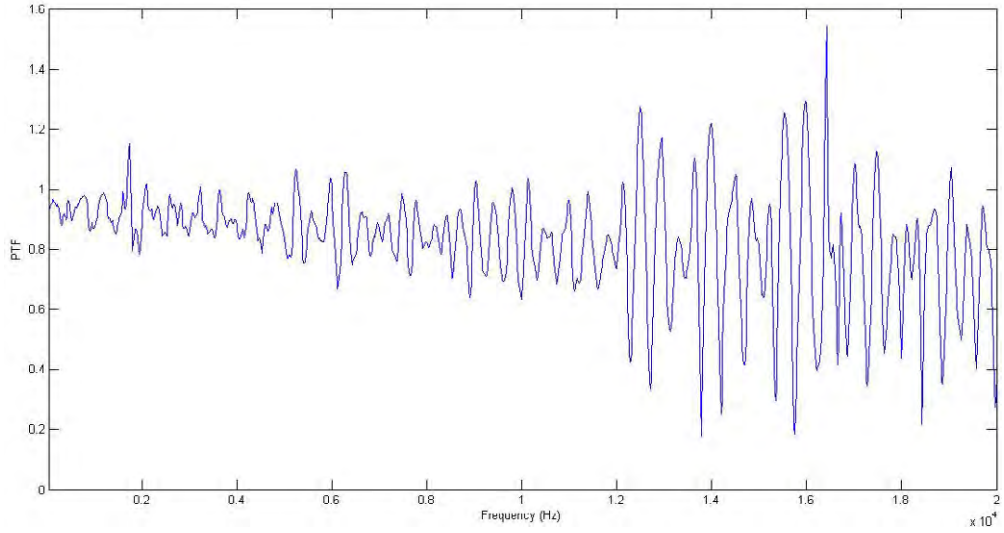

Fig. 3.19: PTF for screen Enlightor 4K at a distance of 30cm

At a distance of 30 cm, the frequencies found with PTF<0.6 were from 12.2 kHz and above

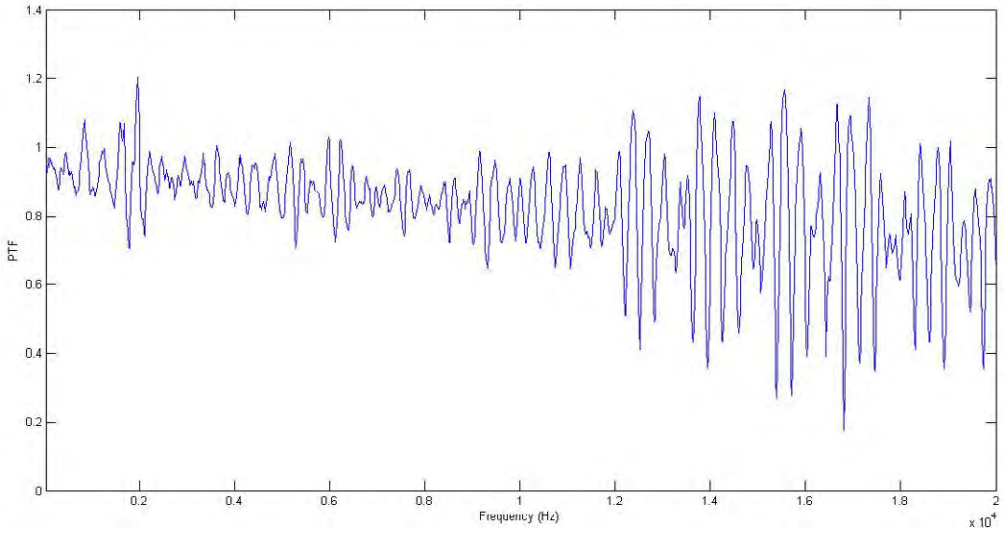

Fig. 3.20: PTF for screen Enlightor 4K at a distance of 45cm

At a distance of 45 cm, the frequencies with PTF<0.6 started at 12.1 kHz

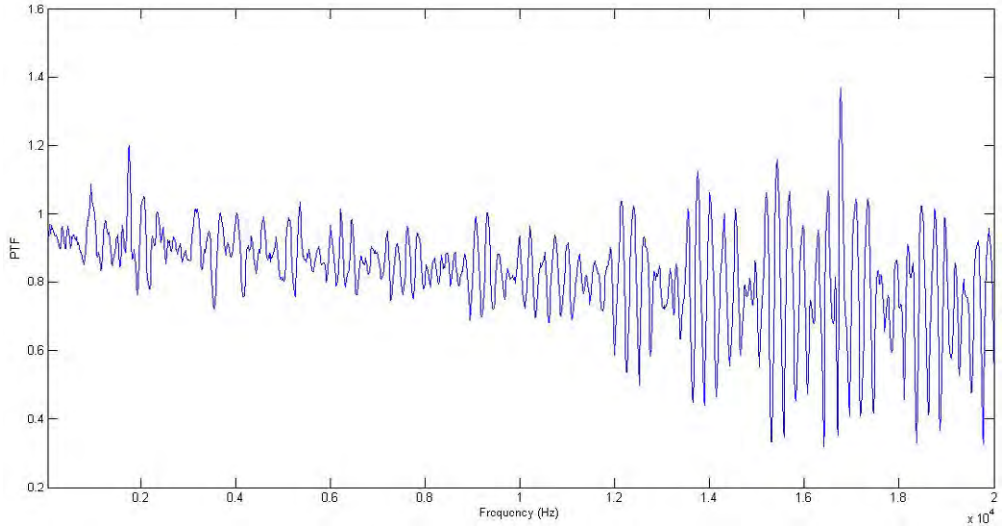

Fig. 3.21: PTF for screen Enlightor 4K at a distance of 60cm

At a distance of 60 cm, the frequencies with PTF<0.6 started at 11.9 kHz

All this data results in the conclusion that the best distance to allocate the screen from the loudspeaker would be 30 c m as the PTF for the lower and m idrange frequencies remains above 0.8.

PTF for screen Matt Plus MiniPerforated

For screen Matt Plus MiniPerforated, PTF at high frequencies is very low and close to 0, which would mean that the screen would be mostly opaque in a wide range of frequencies.

It should be considered that in order to enhance the performance of these kind of screens, an audio processor is normally used which boosts treble to avoid these levels of attenuation.

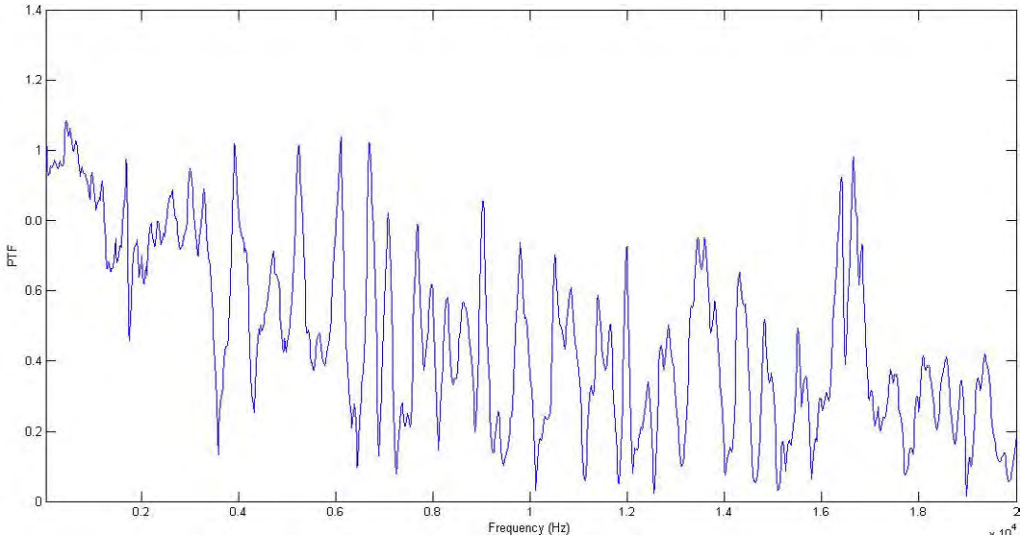

Fig. 3.22: PTF for screen Matt Plus MiniPerforated at a distance of 2 cm

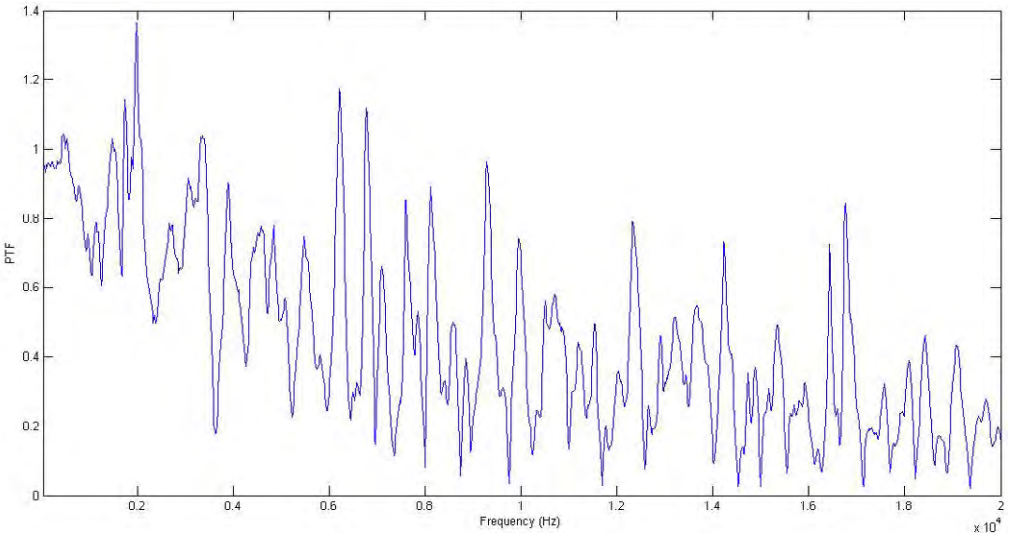

Fig. 3.23: PTF for screen Matt Plus MiniPerforated at a distance of 7 cm

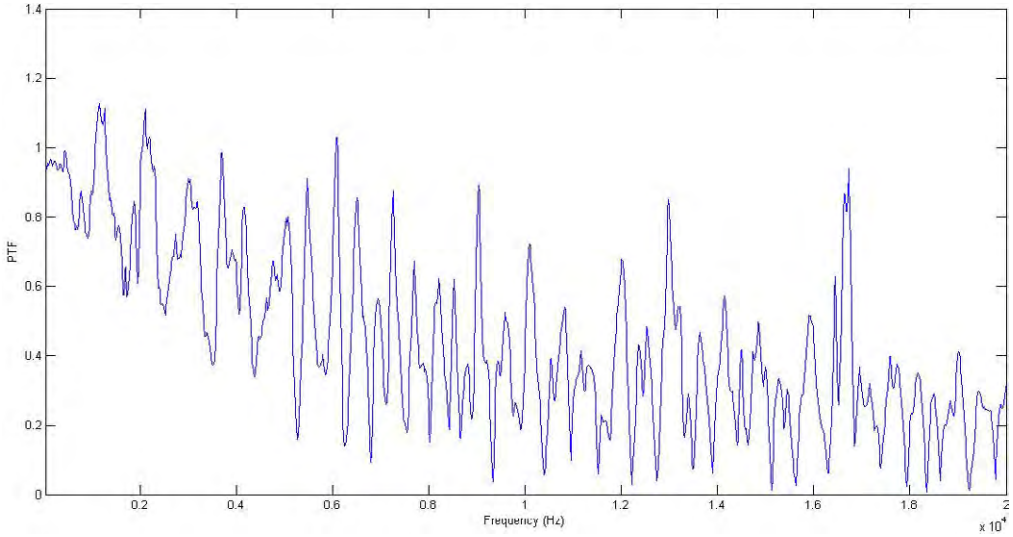

Fig. 3.24: PTF for screen Matt Plus MiniPerforated at a distance of 15 cm

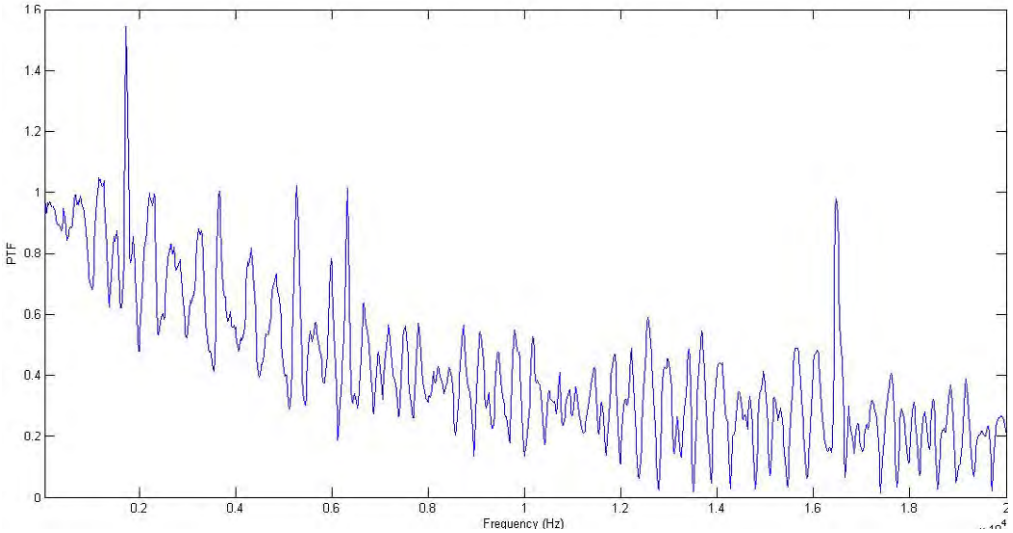

Fig. 3.25: PTF for screen Matt Plus MiniPerforated at a distance of 30 cm

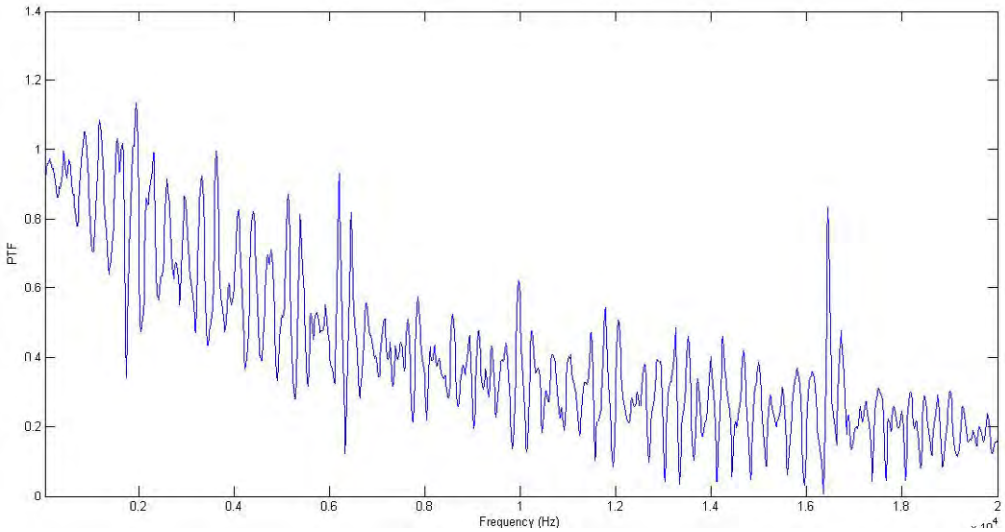

Fig. 3.26: PTF for screen Matt Plus MiniPerforated at a distance of 45 cm

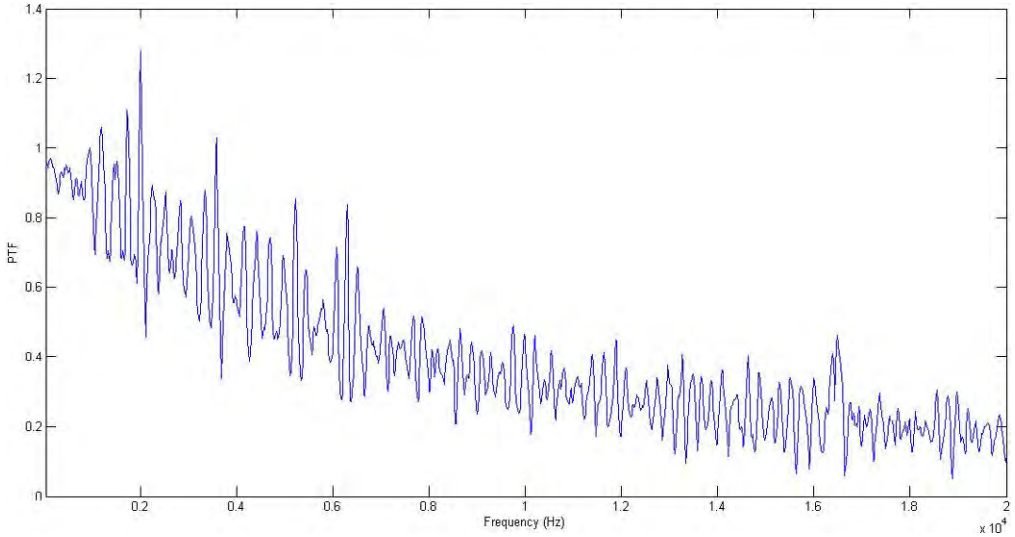

Fig. 3.27: PTF for screen Matt Plus MiniPerforated at a distance of 60 cm

PTF for screen ClearPix 2 White 1.0

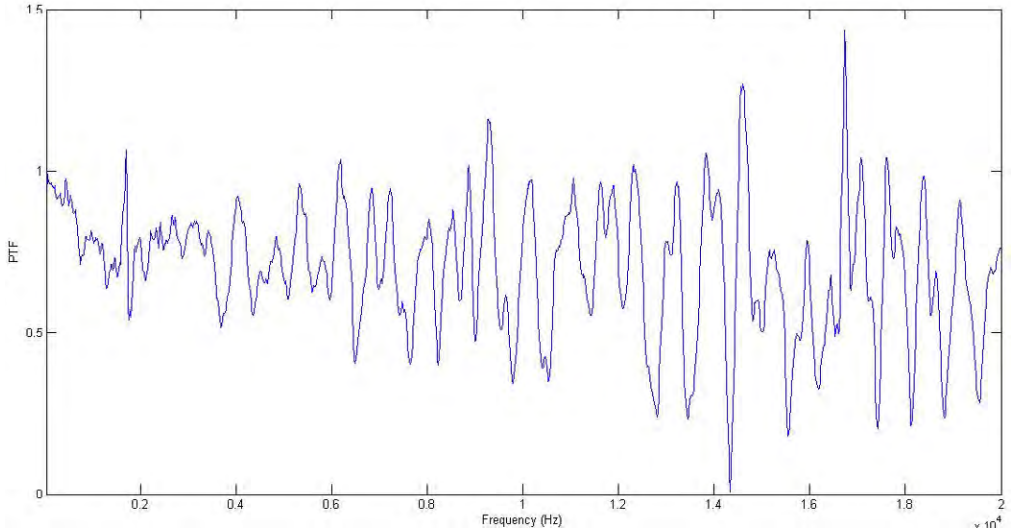

Fig. 3.28: PTF for screen ClearPix 2 White 1.0 at a distance of 2 cm

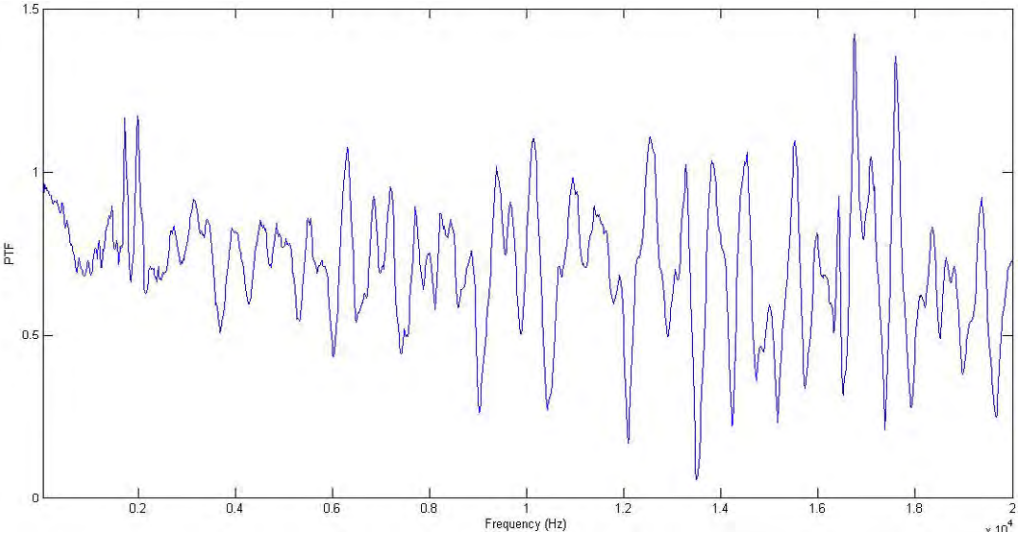

Fig. 3.29: PTF for screen ClearPix 2 White 1.0 at a distance of 7 cm

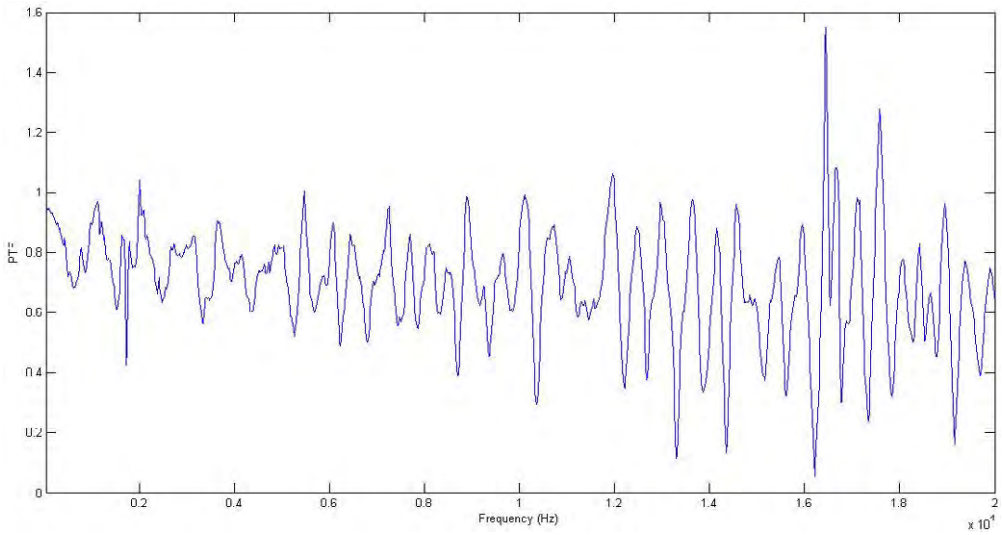

Fig. 3.30: PTF for screen ClearPix 2 White 1.0 at a distance of 15 cm

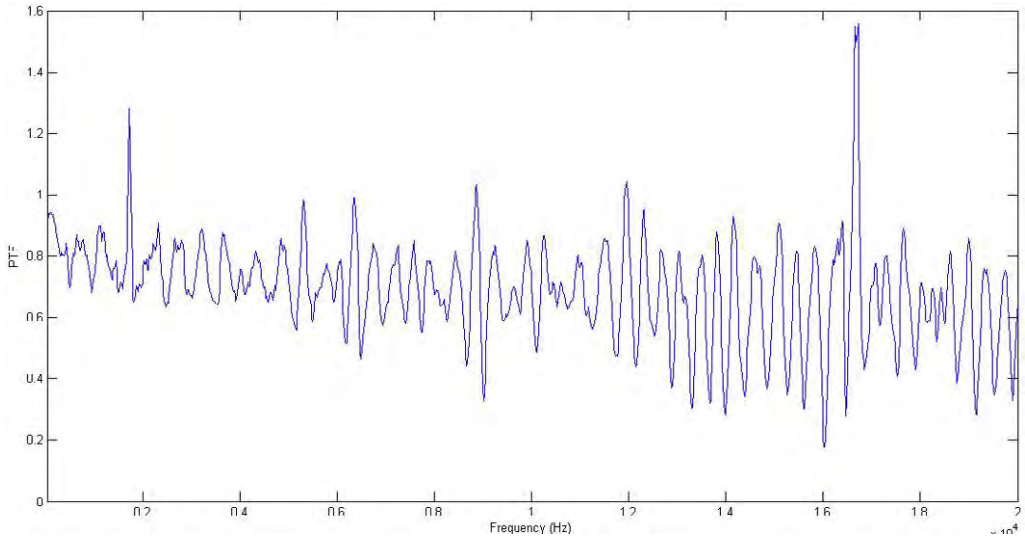

Fig. 3.31: PTF for screen ClearPix 2 White 1.0 at a distance of 30 cm

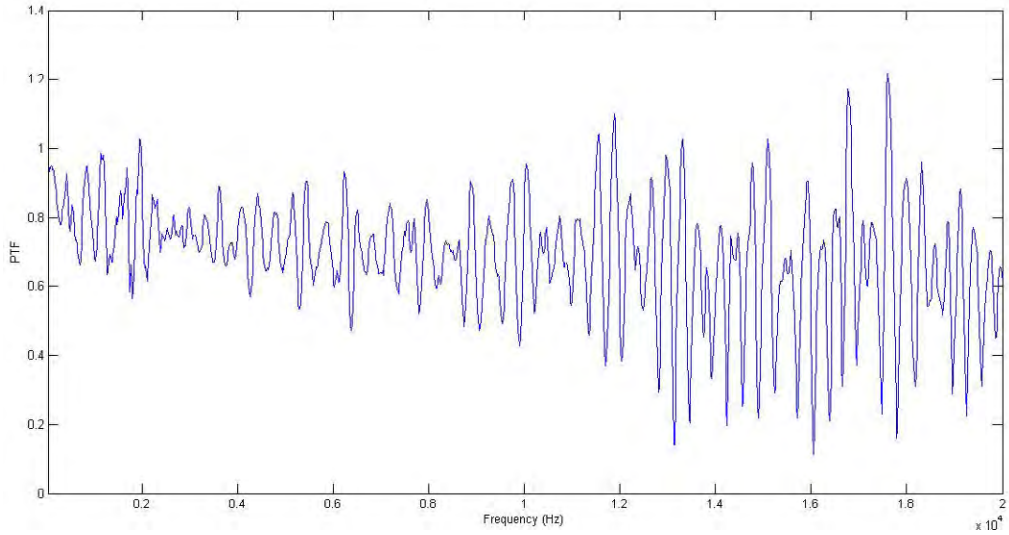

Fig. 3.32: PTF for screen ClearPix 2 White 1.0 at a distance of 45 cm

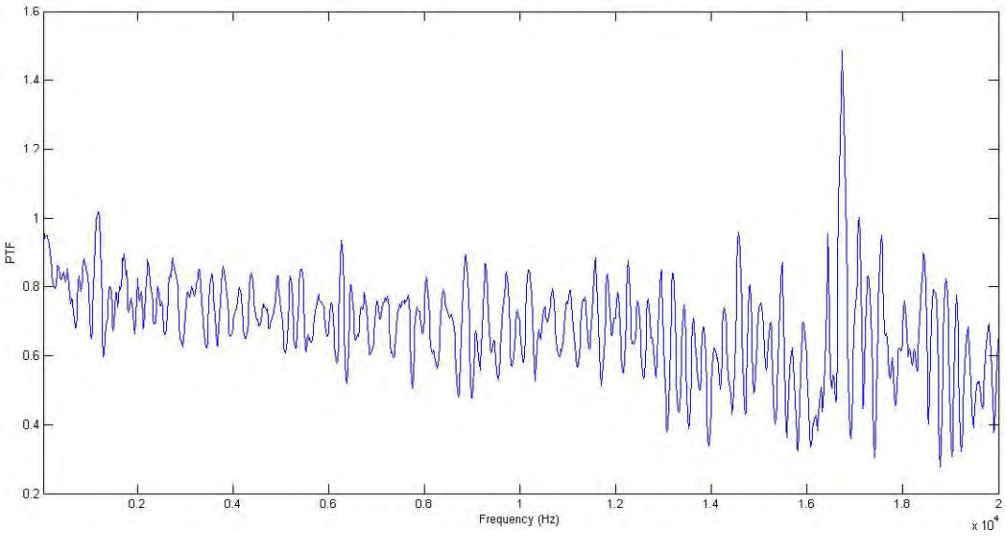

Fig. 3.33: PTF for screen ClearPix 2 White 1.0 at a distance of 60 cm

These results lead to the conclusion that woven screens (Enlightor 4K and ClearPix 2 White 1.0) are more acoustically transparent than the perforated screens which was measured. The perforated screen experiences great losses especially at high frequencies, and its PTF is very low from 6000 Hz onwards; whereas woven screens' PTF is more constant with the exception of some peaks at certain frequencies, which could be caused by comb filtering.

3.3. Frequency Response

Data related to comb filtering was also obtained by representation of the frequency response when the screens were placed at different distances from the loudspeaker as it was previously mentioned.

In the following figures, frequency responses are going to be shown in groups of three. Each group will show the frequency responses for the different screens at the same distance from the loudspeaker measured at 0 degrees. In case the reader wants to look at the frequency responses at different microphone positions (15, 30 and 45 degrees) they can be found on the Appendix A: at the end of this report.

Screens at a distance of 2 cm

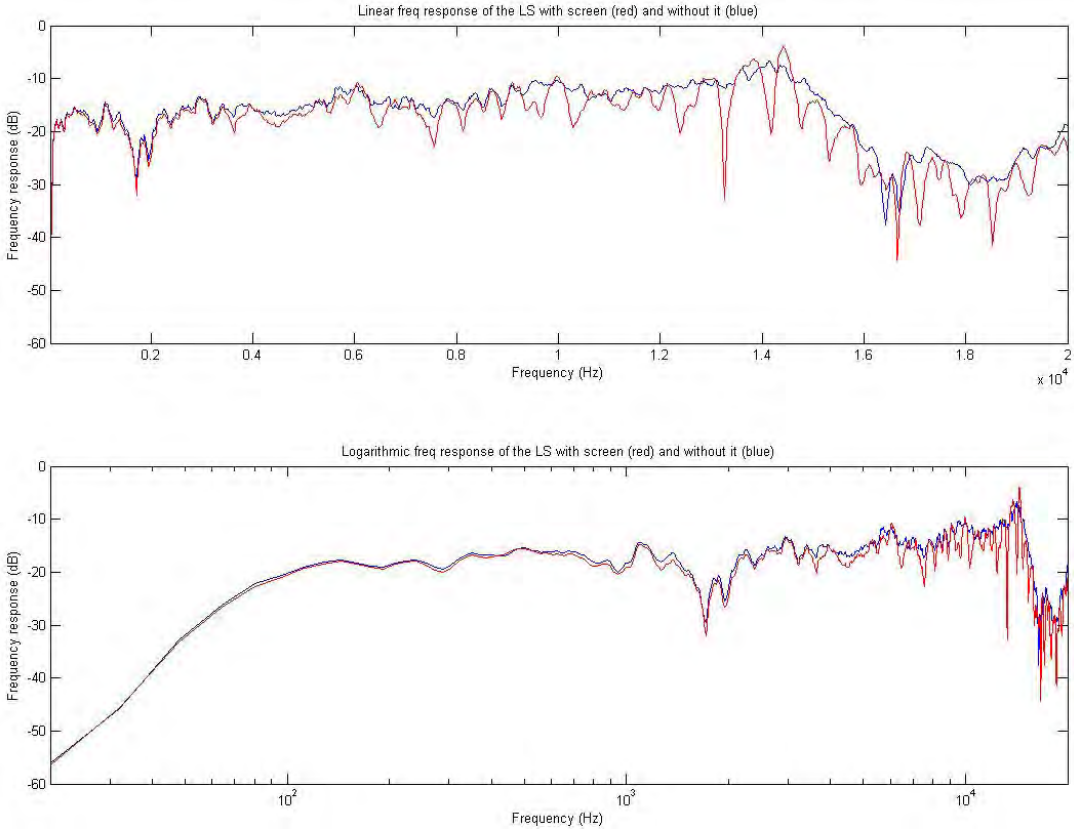

Fig. 3.34: Freq. response for screen Enlightor 4K at a distance of 2cm. 0 degrees

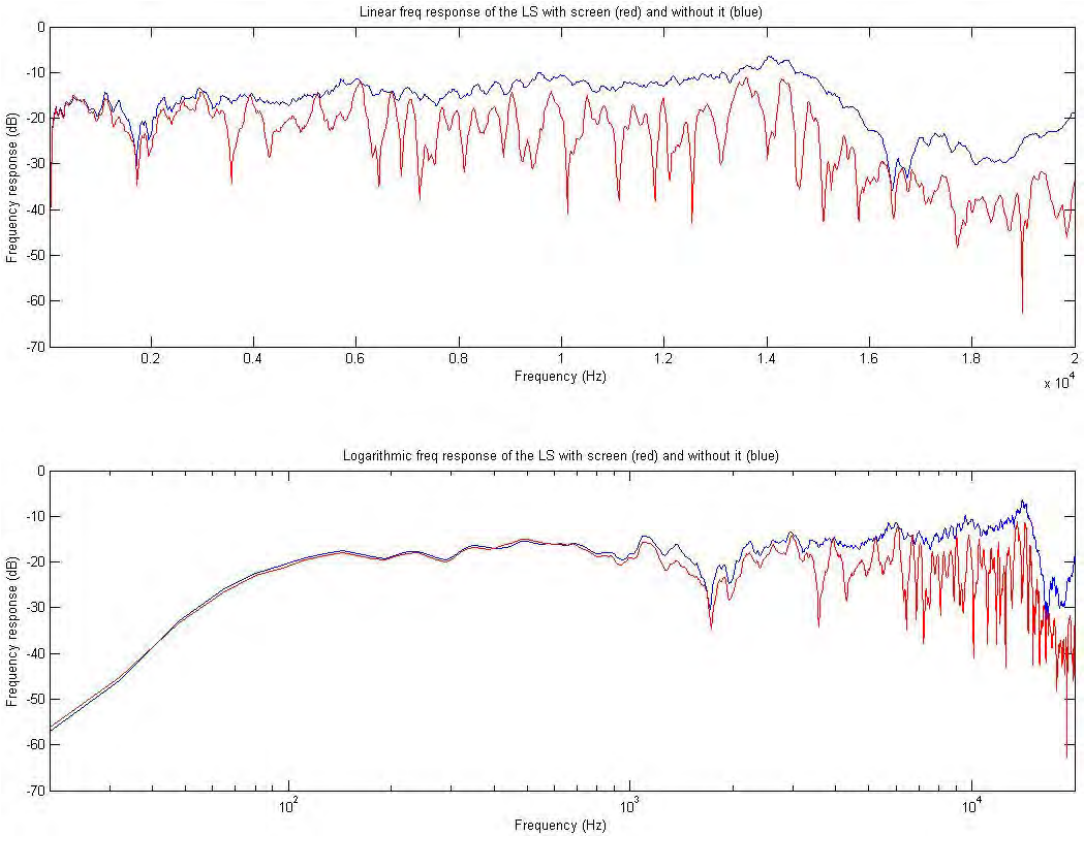

Fig. 3.35 Freq. response for screen Matt Plus Miniperforated at a distance of 2 cm. 0 degrees

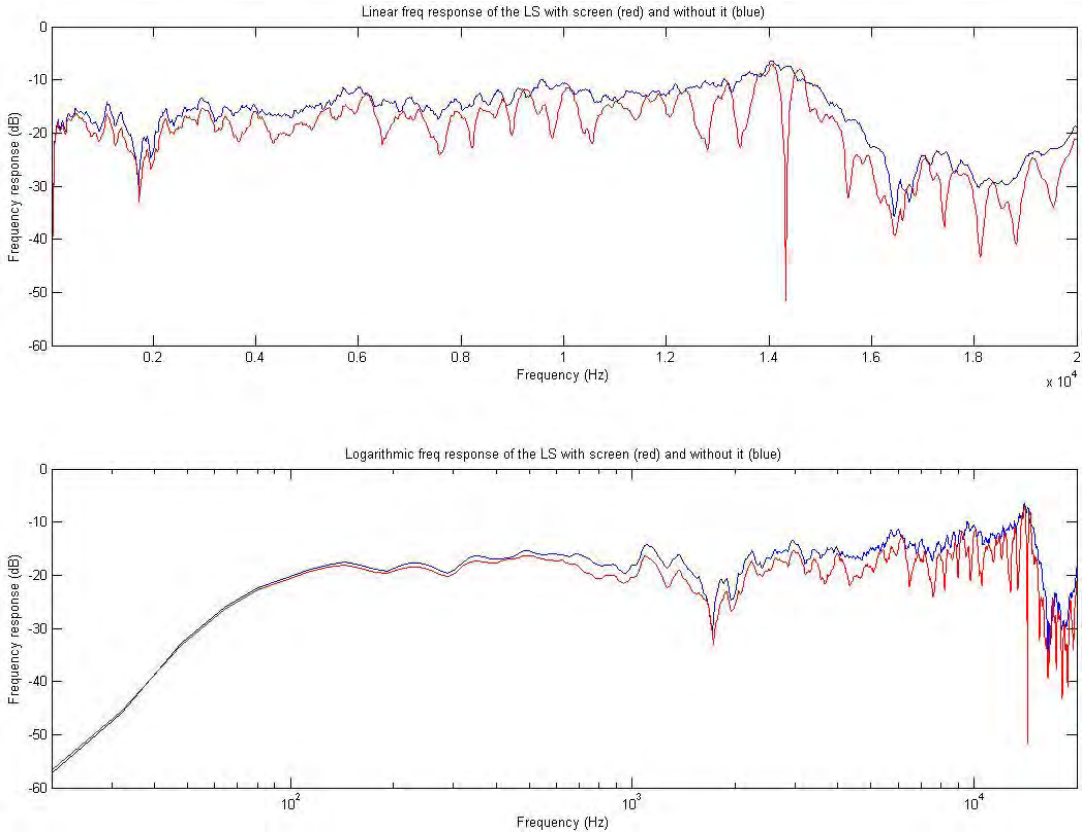

Fig. 3.36: Freq. response for screen ClearPix 2 White 1.0 at a distance of 2 cm. 0 degrees

Screens at a distance of 7 cm

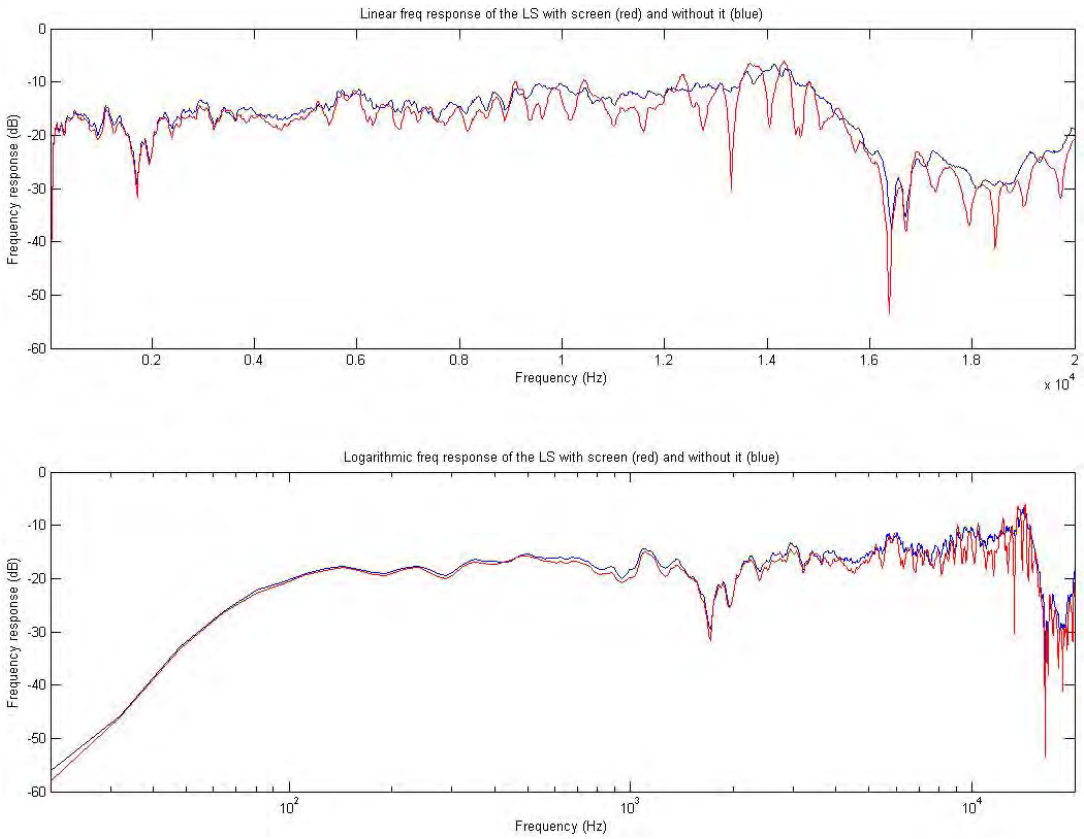

Fig. 3.37: Freq. response for screen Enlightor 4K at a distance of 7cm. 0 degrees

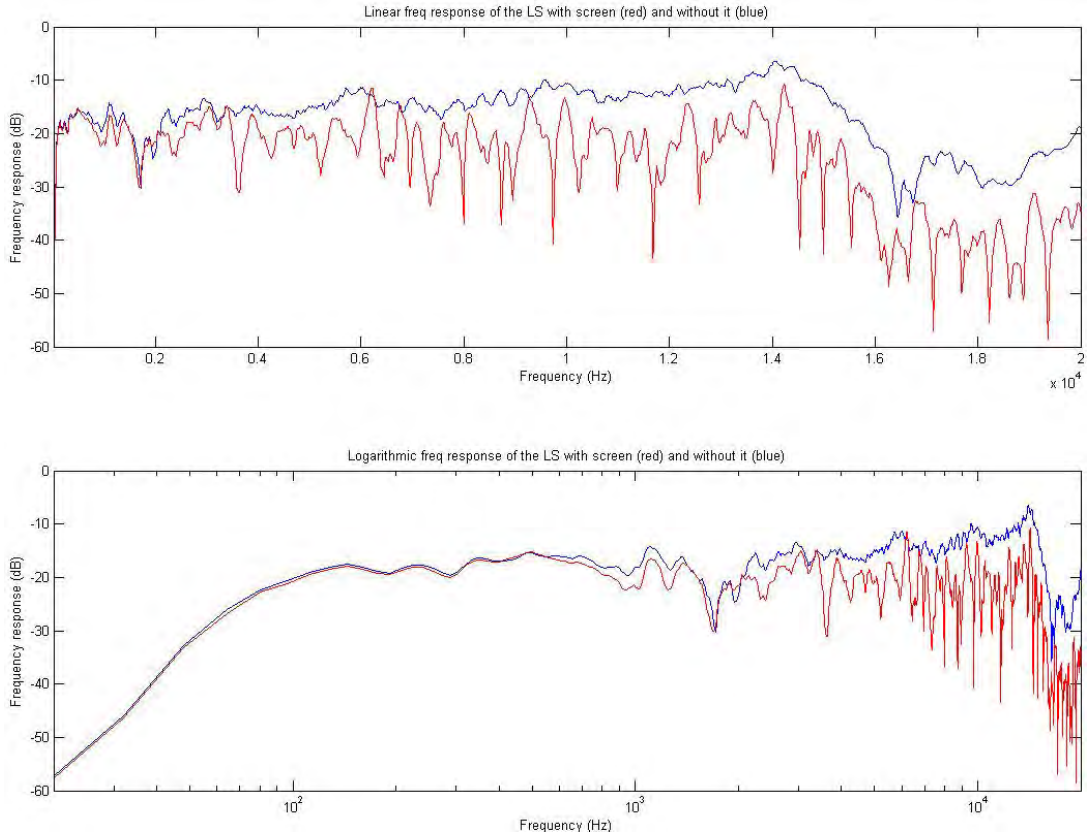

Fig. 3.38: Freq. response for screen Matt Plus Miniperforated at a distance of 7 cm. 0 degrees

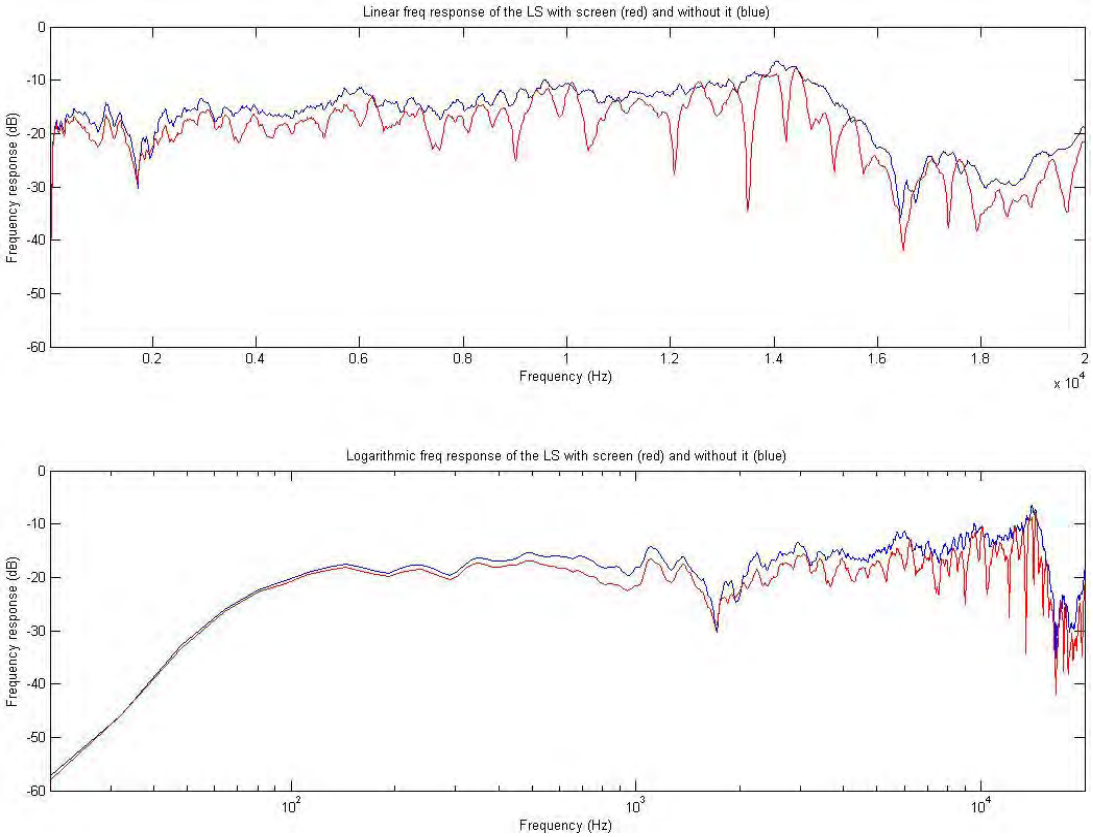

Fig. 3.39: Freq. response for screen ClearPix 2 White 1.0 at a distance of 7 cm. 0 degrees

Screens at a distance of 15 cm

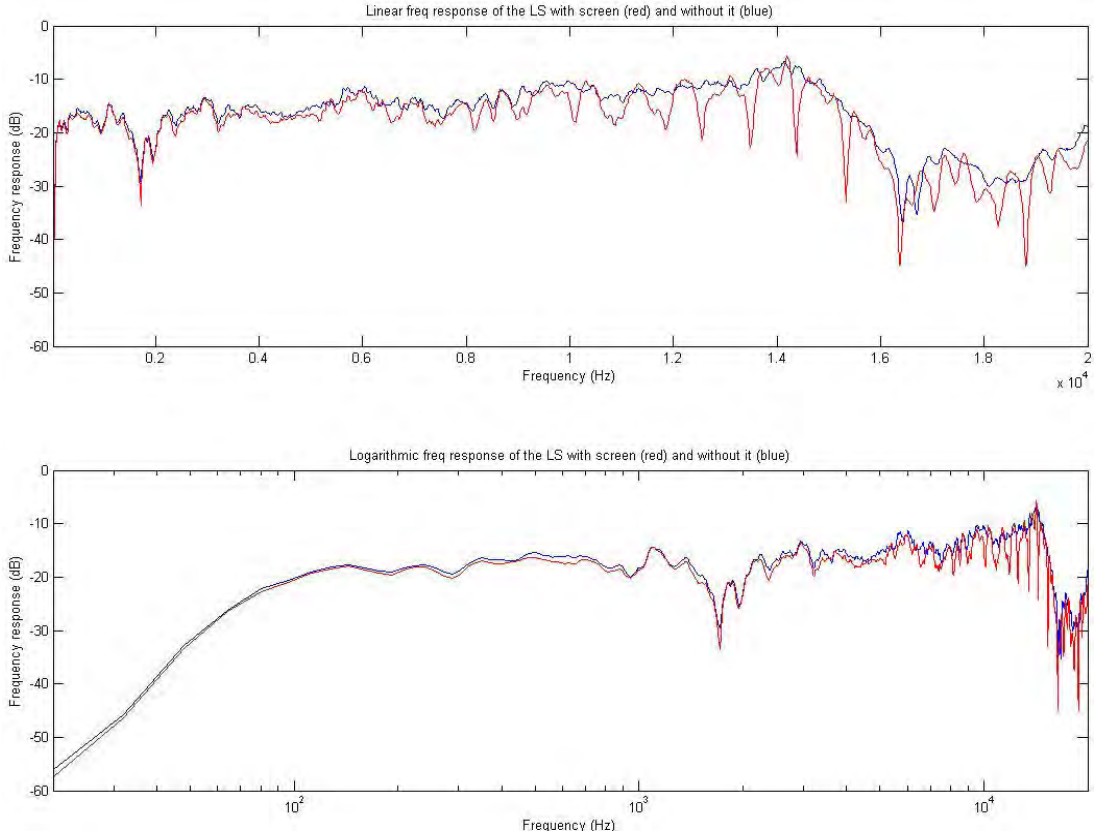

Fig. 3.40: Freq. response for screen Enlightor 4K at a distance of 15cm. 0 degrees

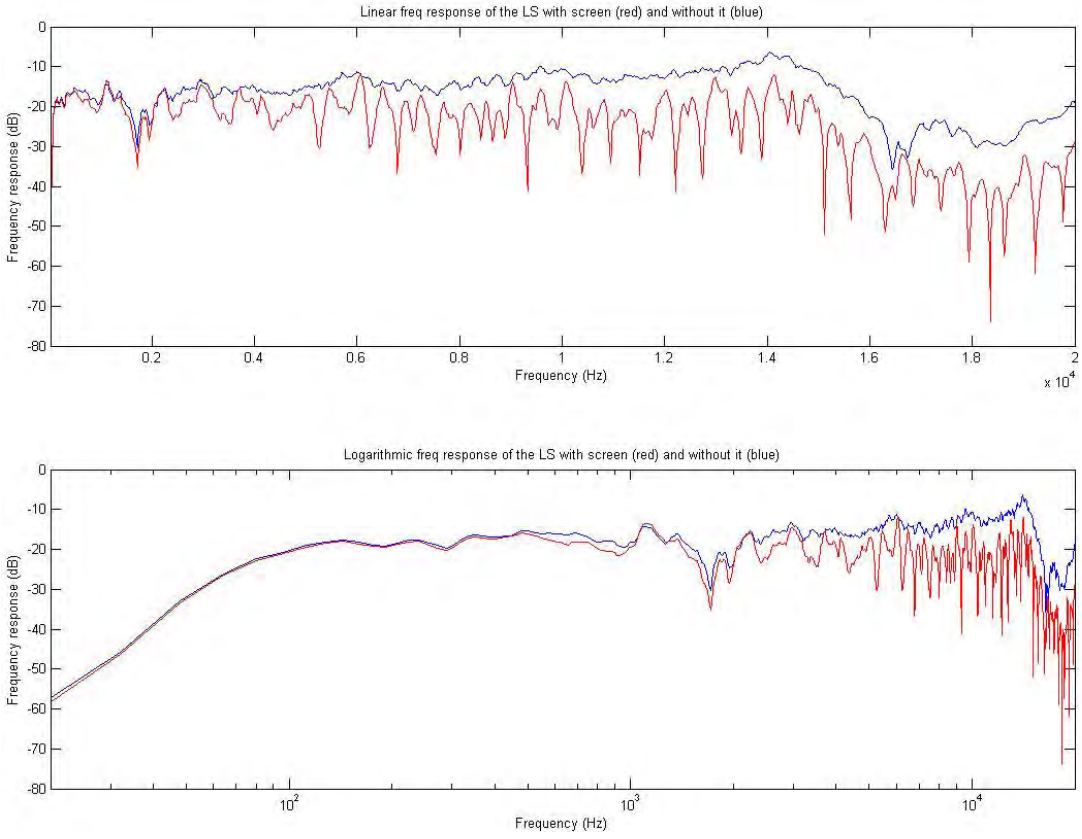

Fig. 3.41: Freq. response for screen Matt Plus Miniperforated at a distance of 15 cm. 0 degrees

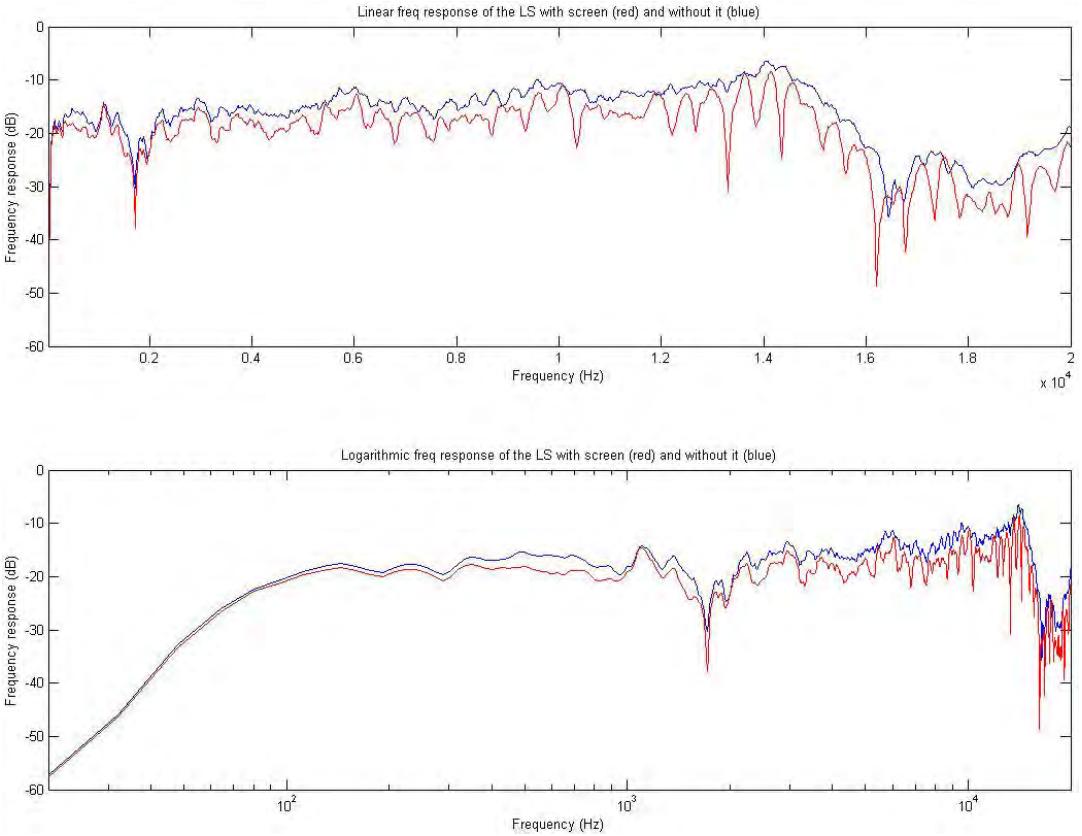

Fig. 3.42: Freq. response for screen ClearPix 2 White 1.0 at a distance of 15 cm. 0 degrees

Screens at a distance of 30 cm

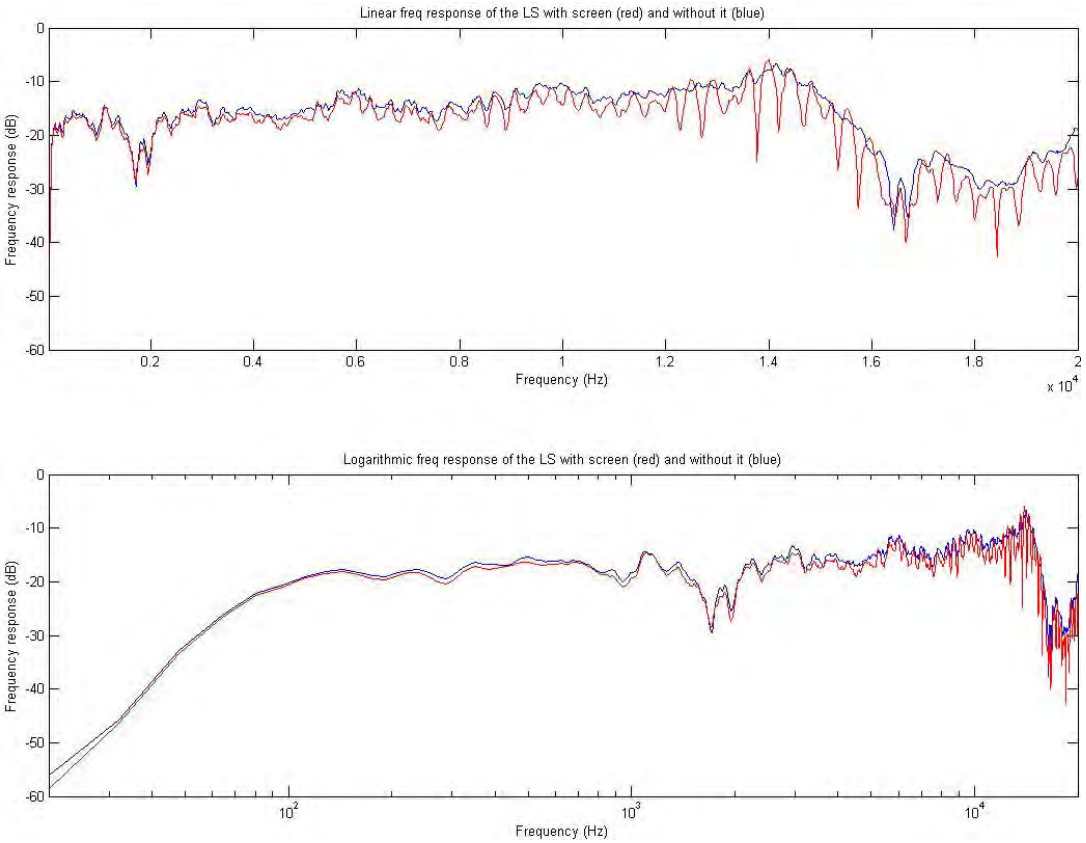

Fig. 3.43: Freq. response for screen Enlightor 4K at a distance of 30cm. 0 degrees

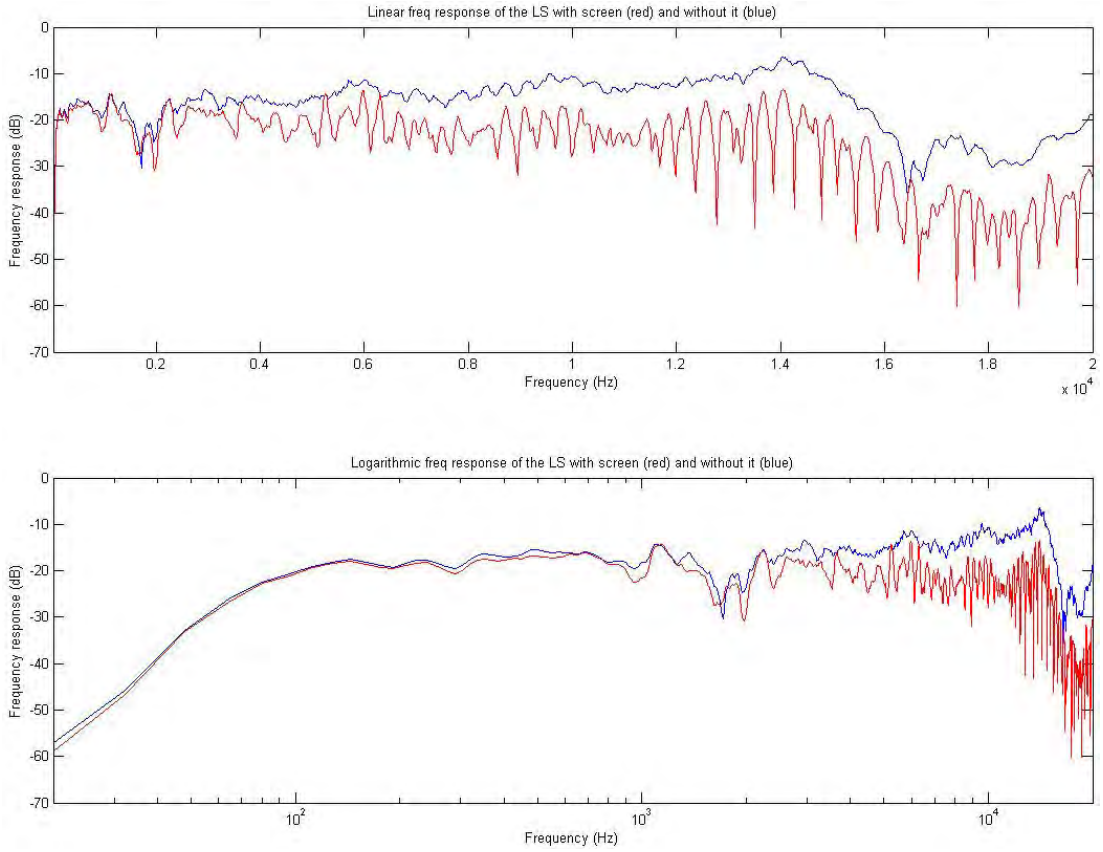

Fig. 3.44: Freq. response for screen Matt Plus Miniperforated at a distance of 30 cm. 0 degrees

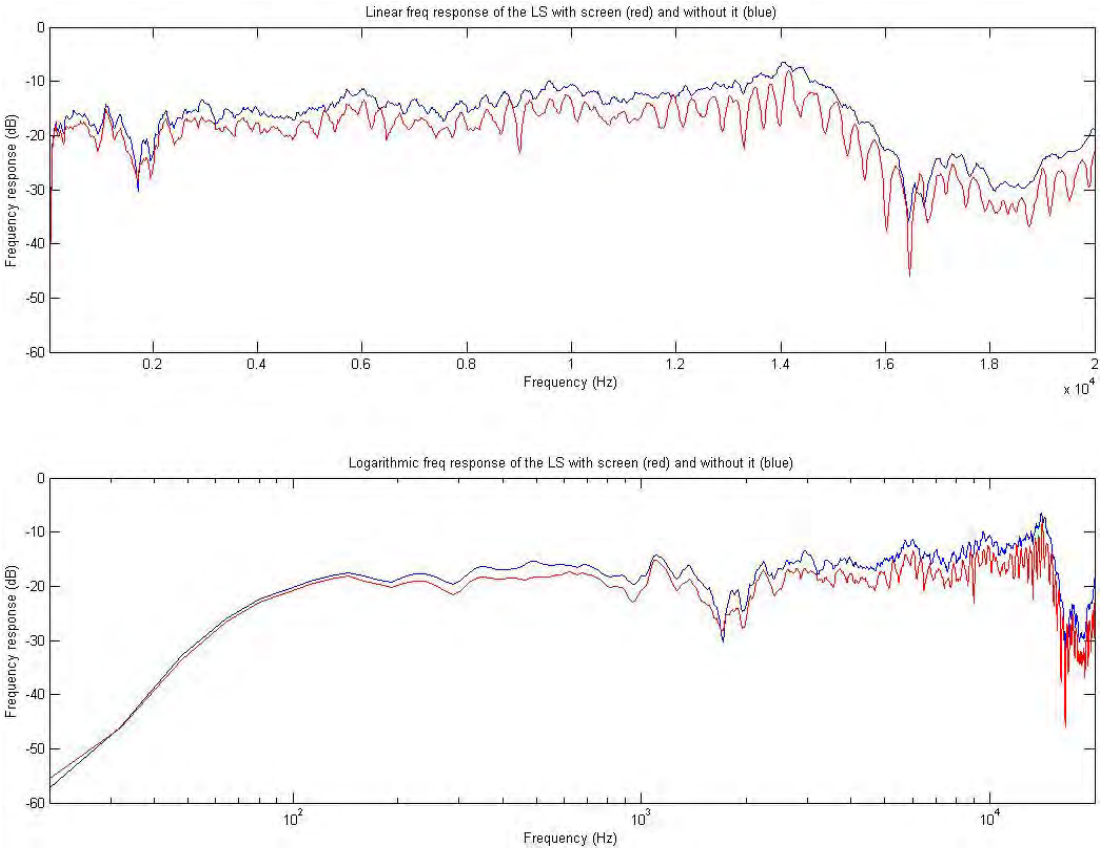

Fig. 3.45: Freq. response for screen ClearPix 2 White 1.0 at a distance of 30 cm. 0 degrees

Screens at a distance of 45 cm

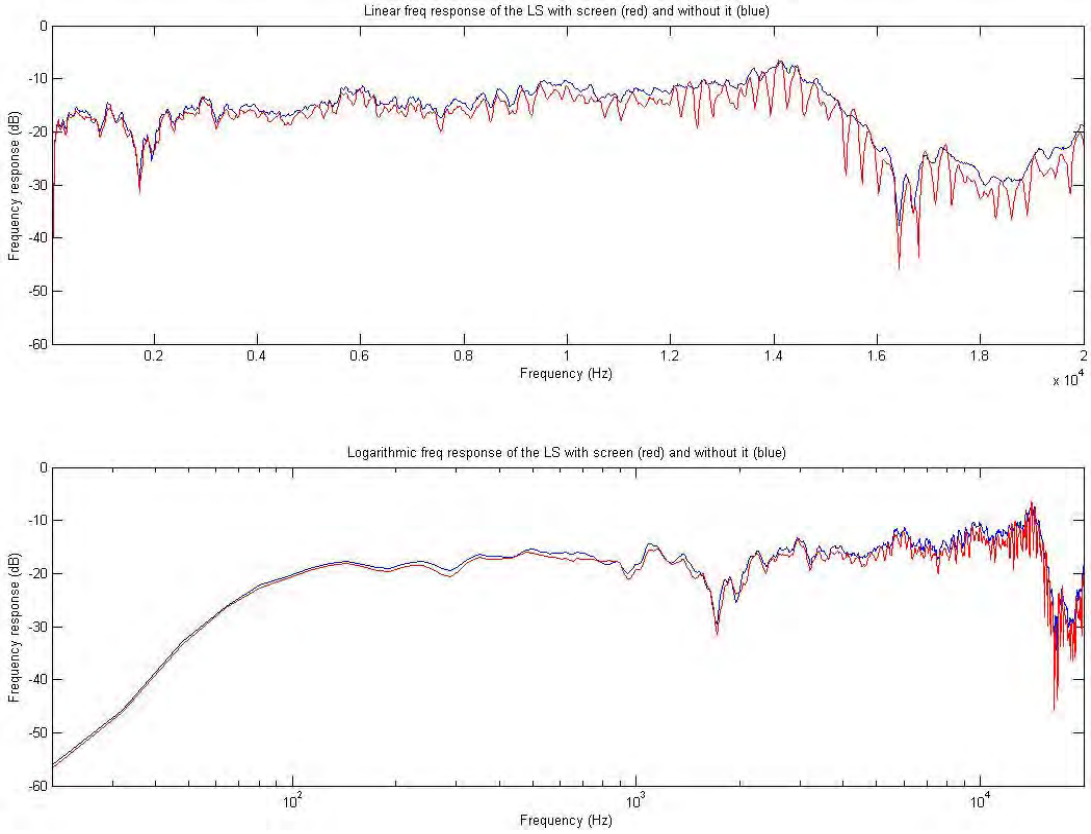

Fig. 3.46: Freq. response for screen Enlightor 4K at a distance of 45cm. 0 degrees

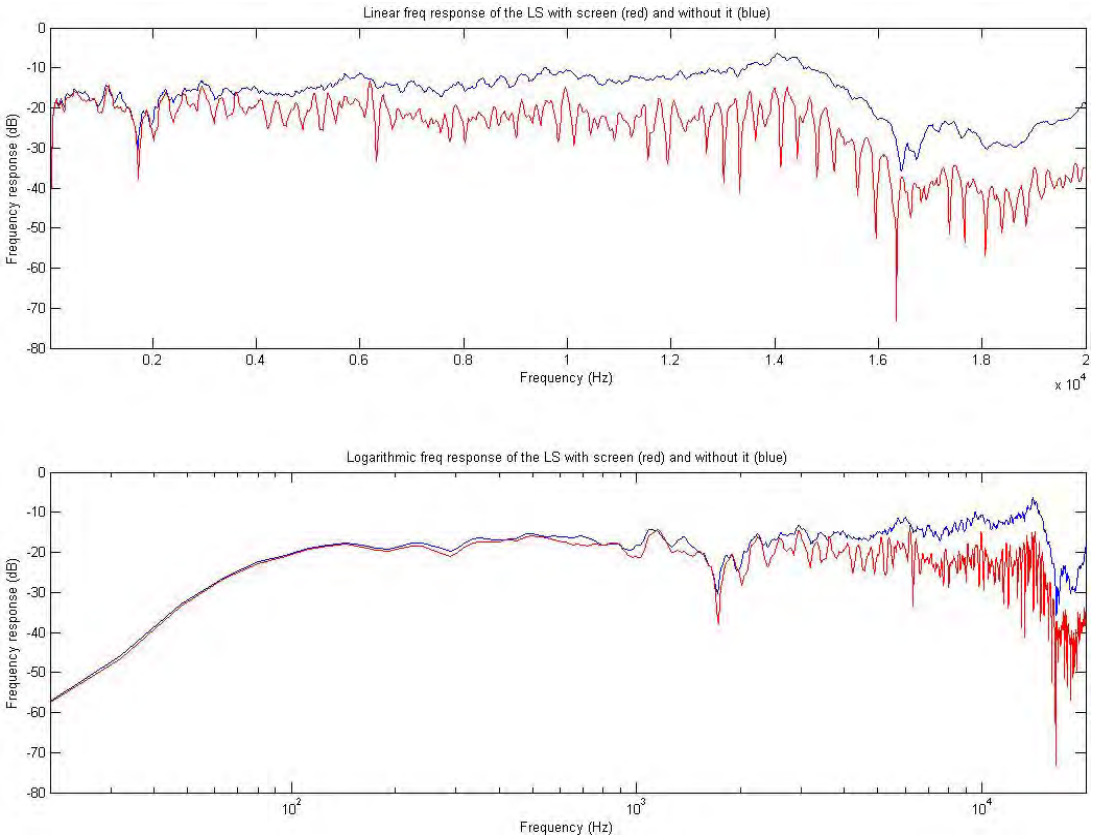

Fig. 3.47: Freq. response for screen Matt Plus Miniperforated at a distance of 45 cm. 0 degrees

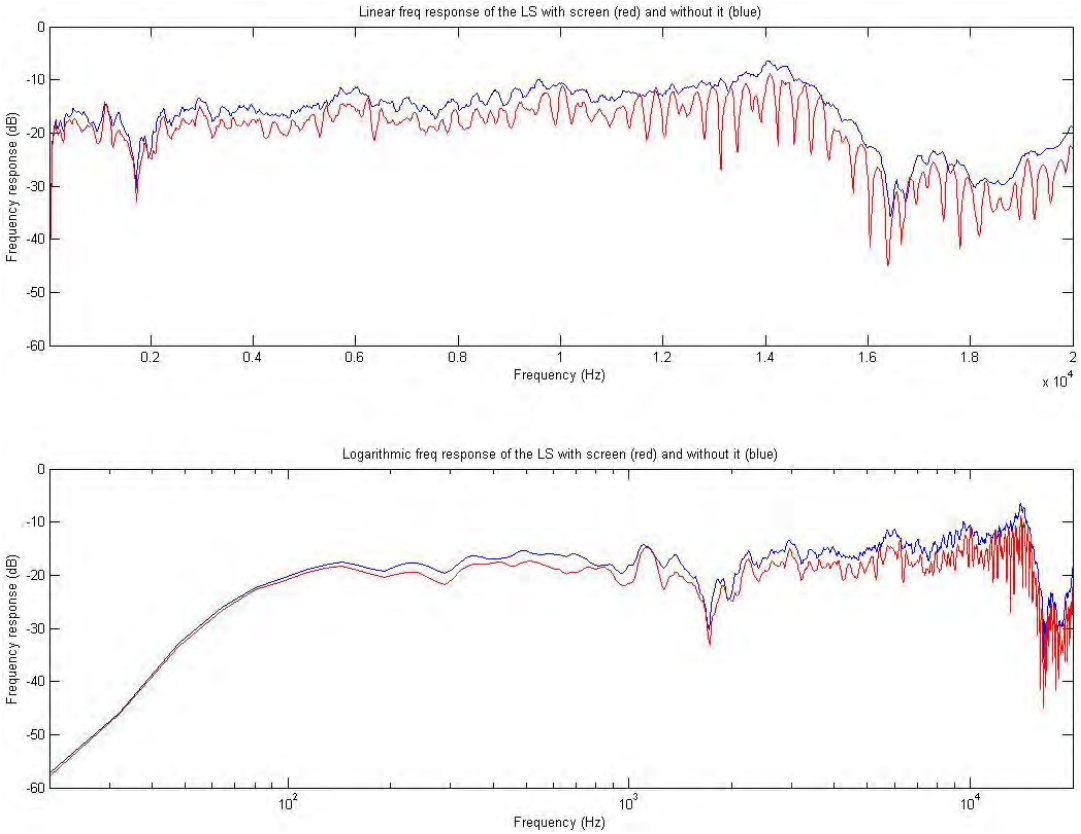

Fig. 3.48: Freq. response for screen ClearPix 2 White 1.0 at a distance of 45 cm. 0 degrees

Screens at a distance of 60 cm

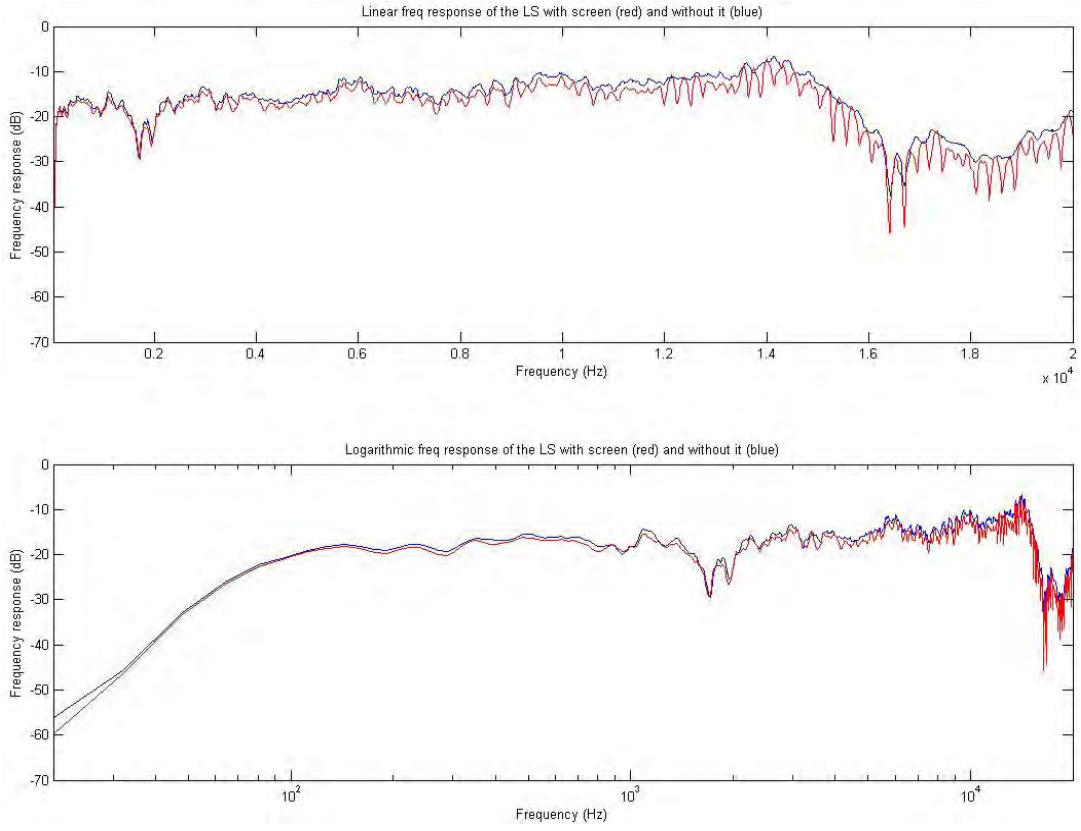

Fig. 3.49: Freq. response for screen Enlightor 4K at a distance of 60cm. 0 degrees

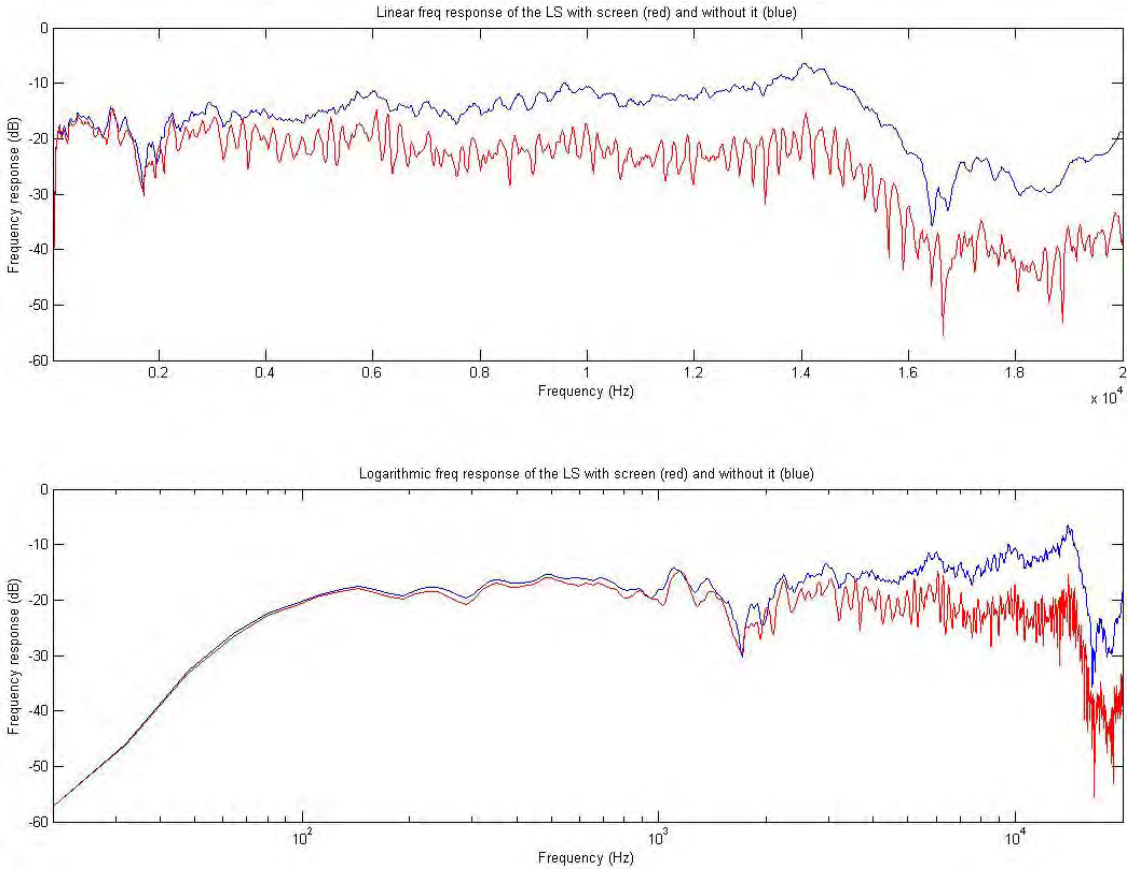

Fig. 3.50: Freq. response for screen Matt Plus Miniperforated at a distance of 60 cm. 0 degrees

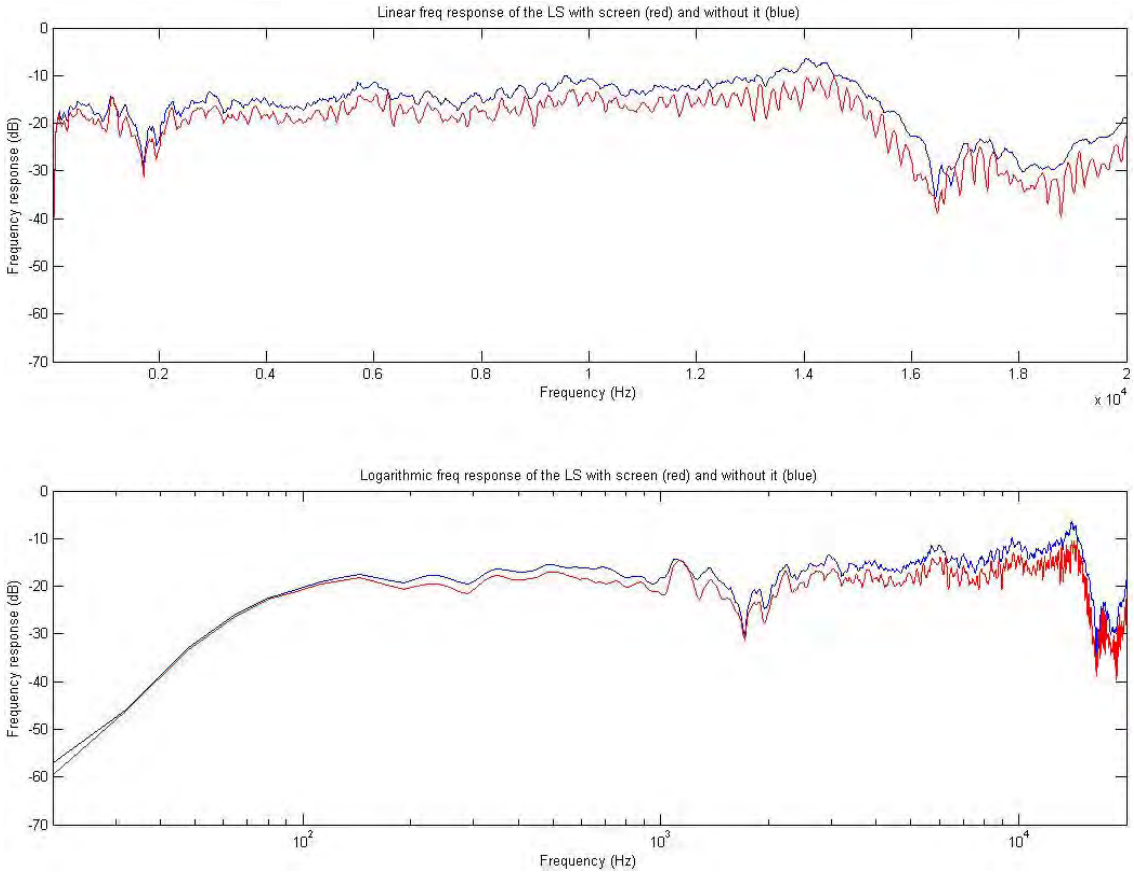

Fig. 3.51: Freq. response for screen ClearPix 2 White 1.0 at a distance of 60 cm. 0 degrees

Screens angled 10 degrees

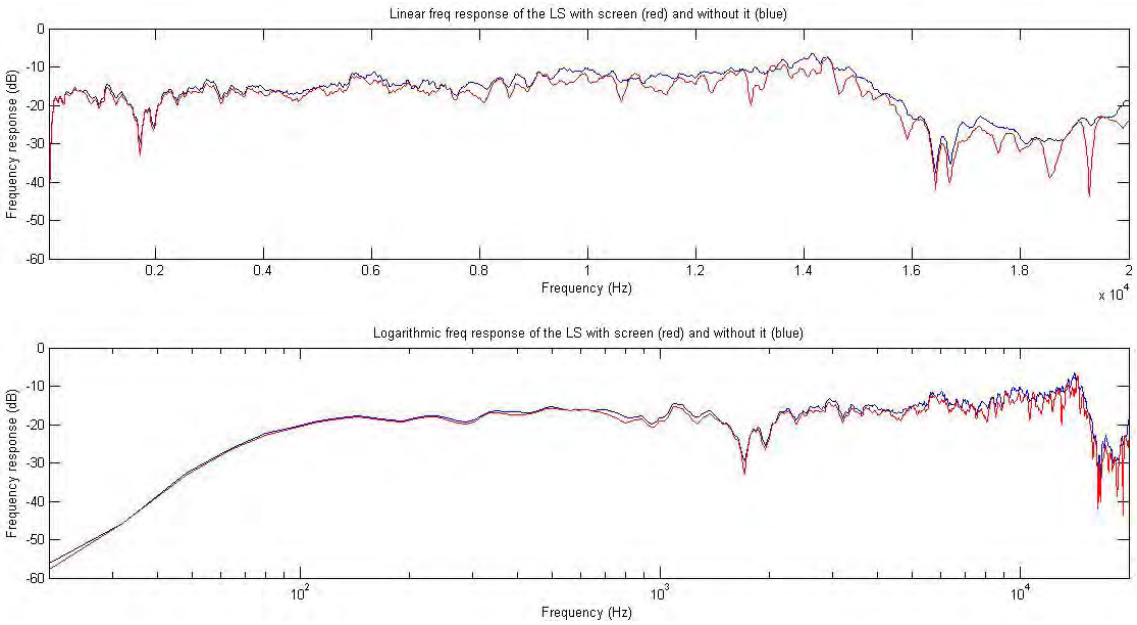

Fig. 3.52: Freq. response for screen Enlightor 4K with screen angled 10 degrees. Mic position 0 degrees

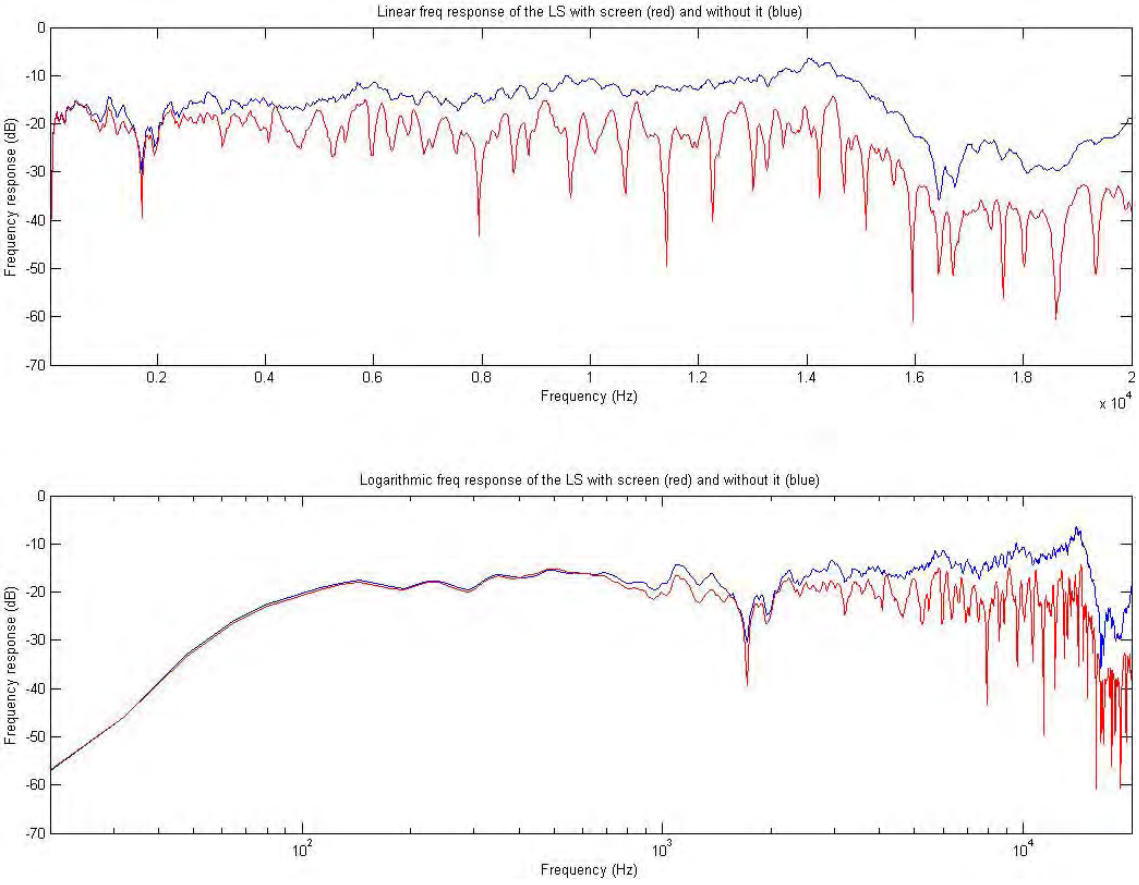

Fig. 3.53: Freq. response for Matt Plus Miniperforated with screen angled 10 degrees. Mic position 0 deg

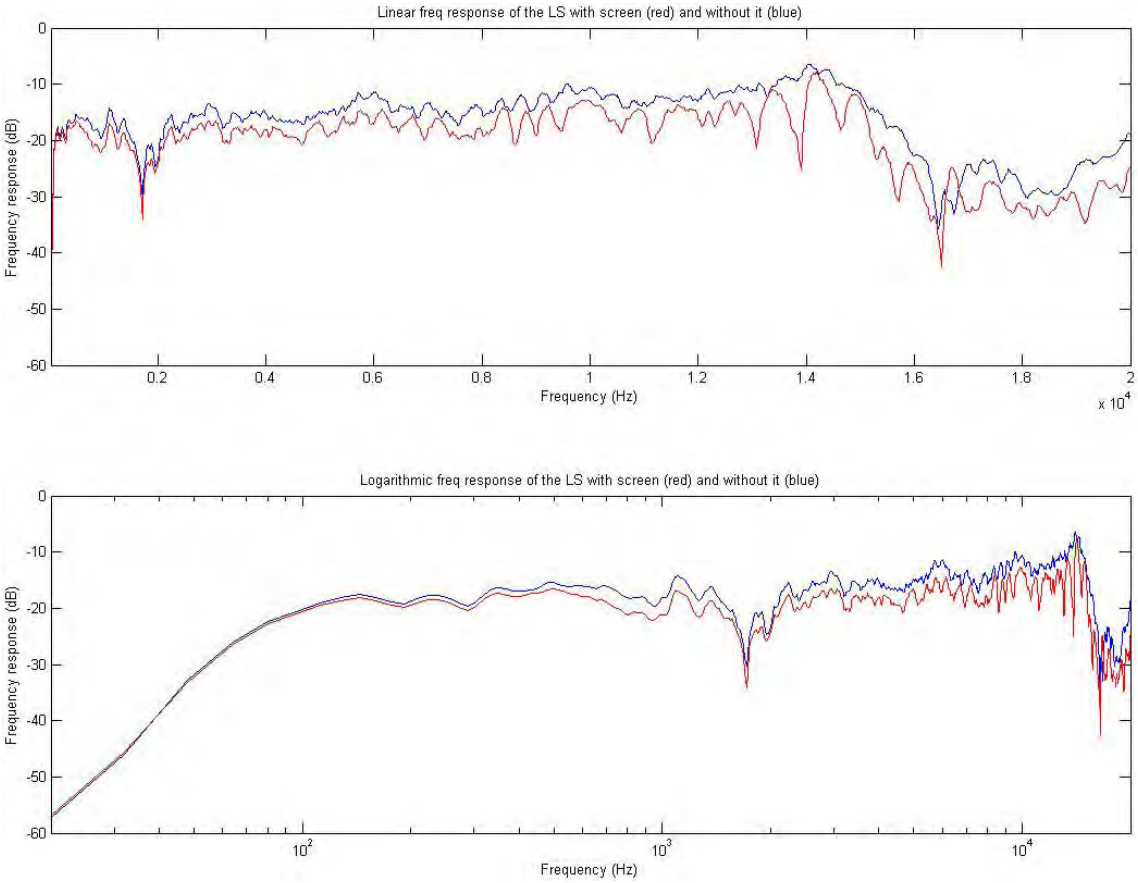

Fig. 3.54: Freq. response for ClearPix 2 White 1.0 with screen angled 10 degrees. Mic position 0 deg

Screens angled 25 degrees

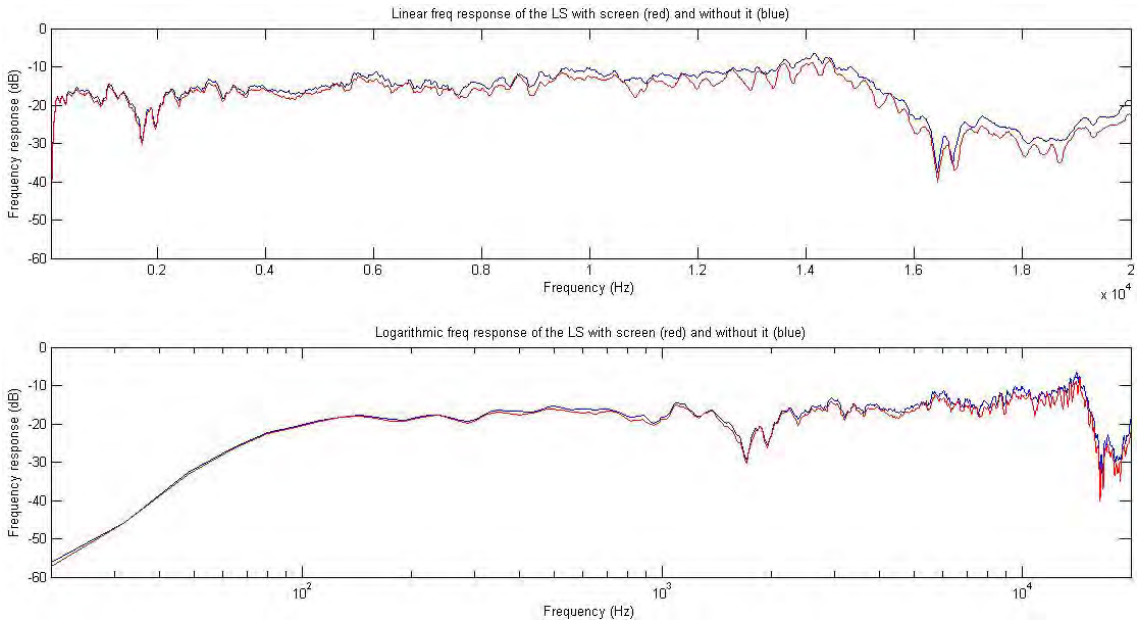

Fig. 3.55: Frequency response for screen Enlightor 4K with screen angled 25 degrees. Mic position 0 deg

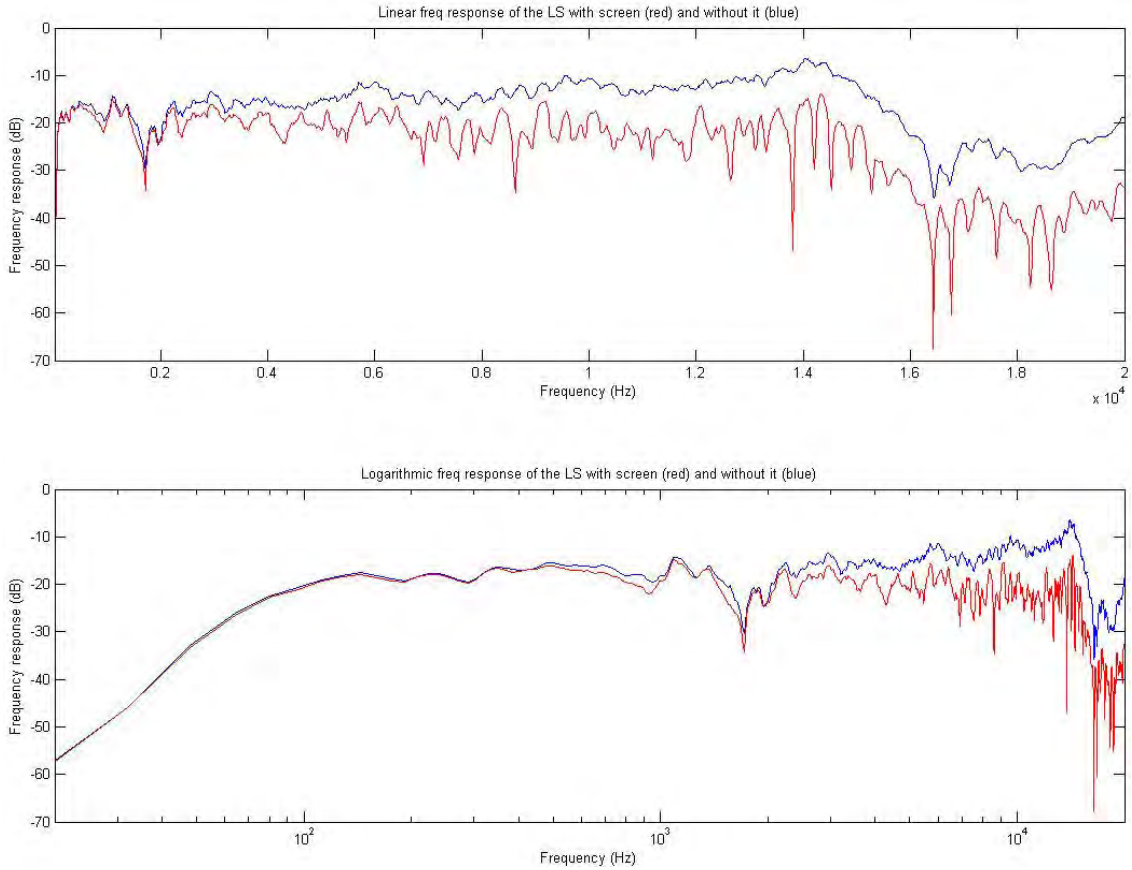

Fig. 3.56: Freq. response for Matt Plus Miniperforated with screen angled 25 degrees. Mic position 0 deg

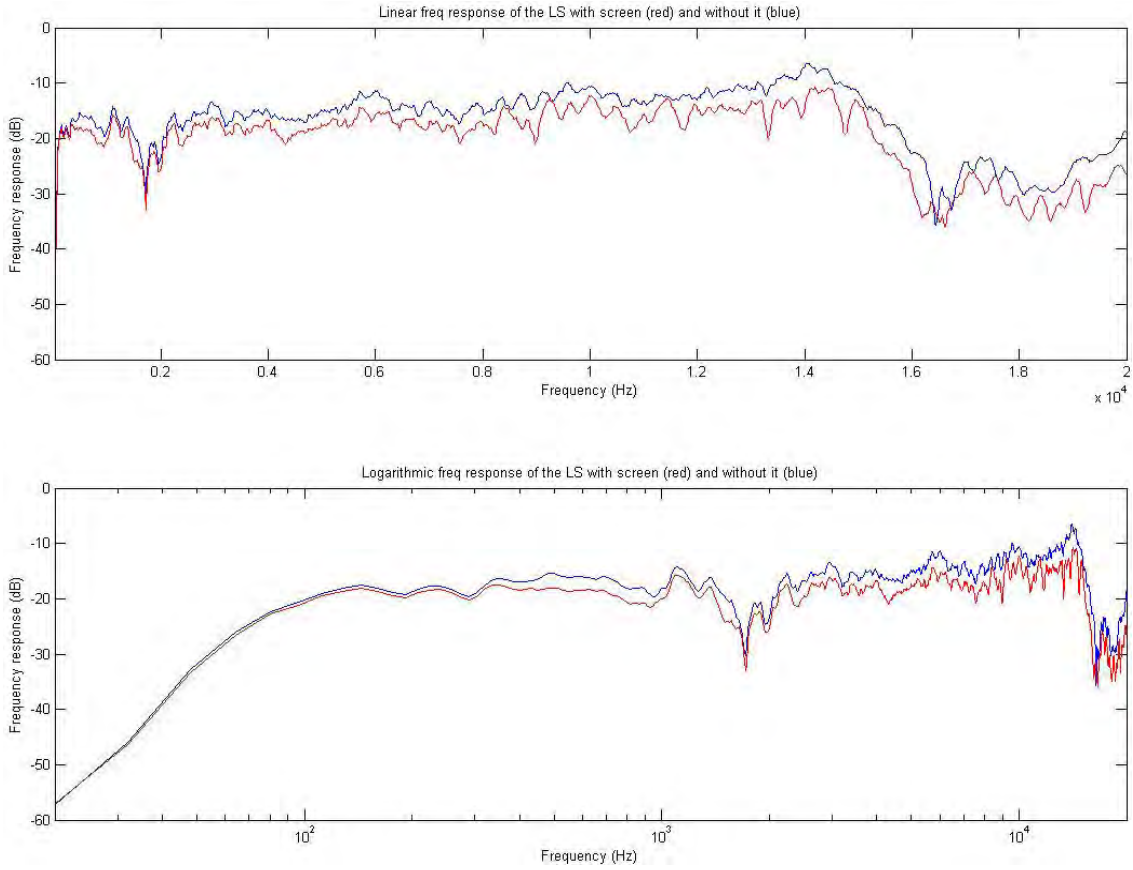

Fig. 3.57: Freq. response for ClearPix 2 White 1.0 with screen angled 25 degrees. Mic position 0 deg

As can be seen through the frequency responses figures, although the comb filtering is noticeable from the moment that a screen is placed between the loudspeaker and the microphone, when the perforated screen is in between, the comb filtering is of great amplitude apart from the obvious attenuation introduced at high frequencies, which will be analysed in more depth in the following section. Woven screens present amplitude differences between peaks and dips in the frequency response of up to 10 dB; whereas when the screen analysed is the perforated one, these differences in amplitude are increased up to 20 dB, leading to noticeable audible problems when films are reproduced.

It is interesting the fact that when screens are angled 10 and 25 degrees with respect to the loudspeaker, comb filtering seems to be considerably reduced in woven screens.

3.4. Attenuation

Acoustic attenuation is a measure of the loss of sound when propagating in media. Sound through partitions can be transmitted, reflected and/or absorbed. Attenuation is the difference between the incident and transmitted sound which would be equal to the reflected and absorbed sound. As manufacturers explain in datasheets, screens introduce an attenuation in the emitted sound. This attenuation is frequency variant, and of course, will not be the same at different distances between the loudspeaker and the screen.

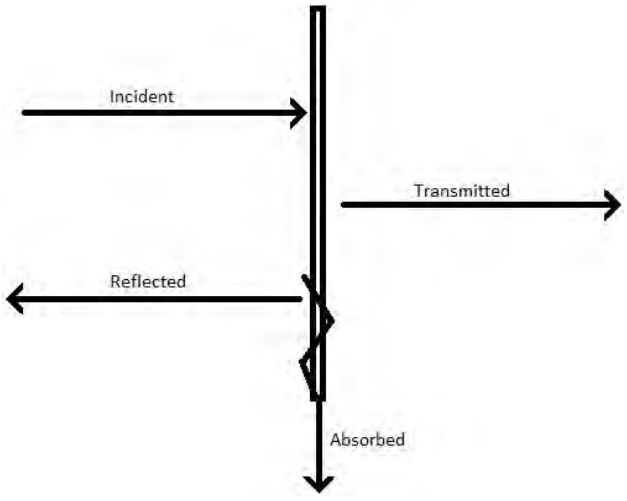

Fig. 3.58: Idealised model of normal incidence sound transmission

$$Attenuation = Incident - Transmitted = Reflected + Absorbed \quad (3.3)$$

As the attenuation is always expressed in decibels, the equation should be like follows,

$$Attenuation = 20 \log \frac{Incident}{Transmitted} \quad (3.4)$$

However, in this project measurements were taken with just one microphone at 0 degrees position. This means the attenuation introduced by the screen will be the difference between the measurement taken with and without the screen as shown in equation (3.5)

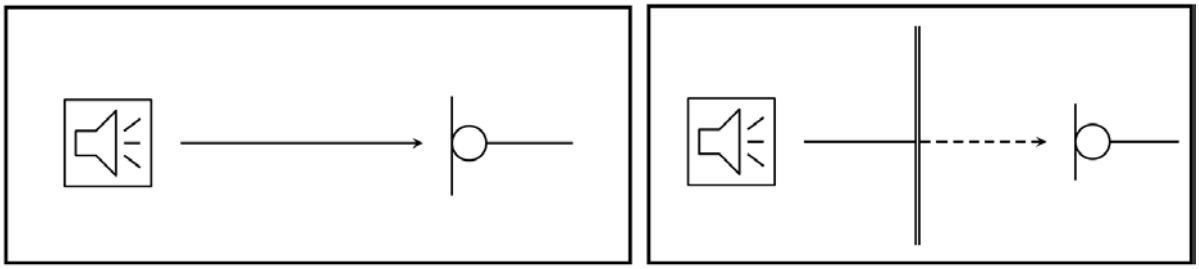

Fig. 3.59: Measurement taken without screen (left) and with screen (right)

$$Attenuation = 20 \log \left| \frac{Measurement\ without\ screen}{Measurement\ with\ screen} \right| \quad (3.5)$$

Attenuation for screen Enlightor 4K

As Fig. 2.2 showed, Screen Excellence ensures that the maximum loss for screen Enlightor 4K is 2.5 dB; however, it does not say at which distance was the screen located or at which frequency was this loss found, which would be information of great help. As can be seen in Table 1, this maximum loss varies according to the distance between loudspeaker and screen. Attenuation figures for screen Enlightor 4K can be found in next page.

Further figures for different microphone positions can be found in Appendix B.

Table 1: Attenuation measured at different distances for different frequencies, Enlightor 4K

Distance	Attenuation (dB) at 100 Hz	Attenuation (dB) at 5 kHz	Attenuation (dB) at 10 kHz	Attenuation (dB) at 16 kHz
2 cm	-0,74	-0,90	-1,39	-2,40
7 cm	-0,60	-0,78	-1,57	-1,60
15 cm	-0,56	-0,95	-1,41	-2,32
30 cm	-0,78	-0,82	-1,44	-1,71
45 cm	-0,58	-0,90	-1,41	-1,92
60 cm	-0,66	-0,90	-1,41	-1,86
10 deg	-0,23	-1,07	-1,52	-3,46
25 deg	-0,96	-1,13	-1,88	-2,37

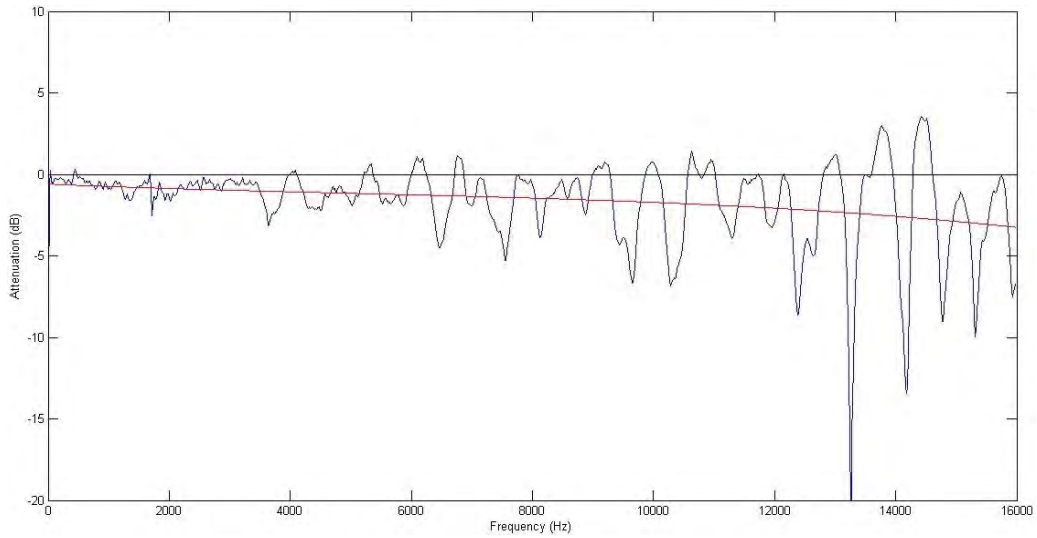

Fig. 3.60: Attenuation for screen Enlightor 4K at a distance of 2 cm, 0 degrees.

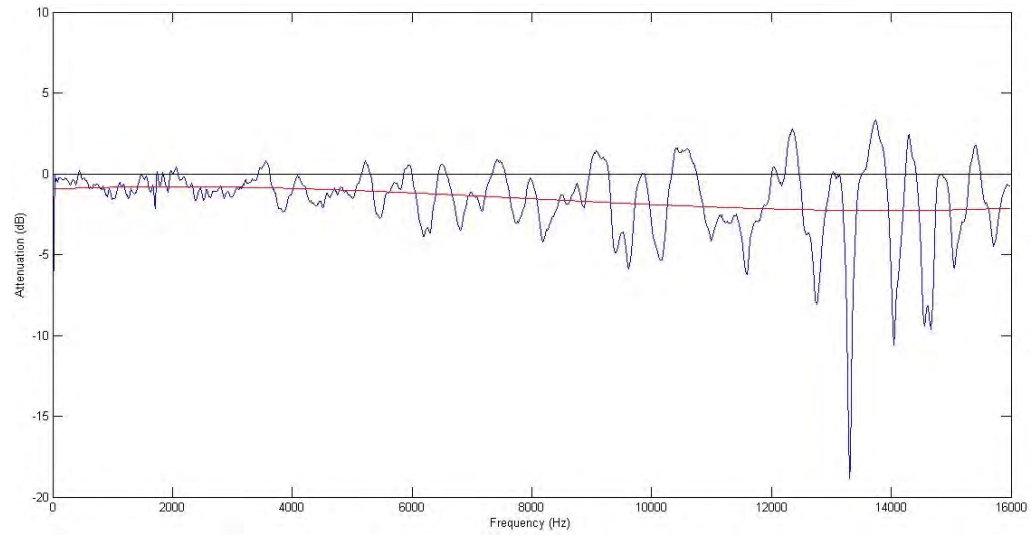

Fig. 3.61: Attenuation for screen Enlightor 4K at a distance of 7 cm, 0 degrees.

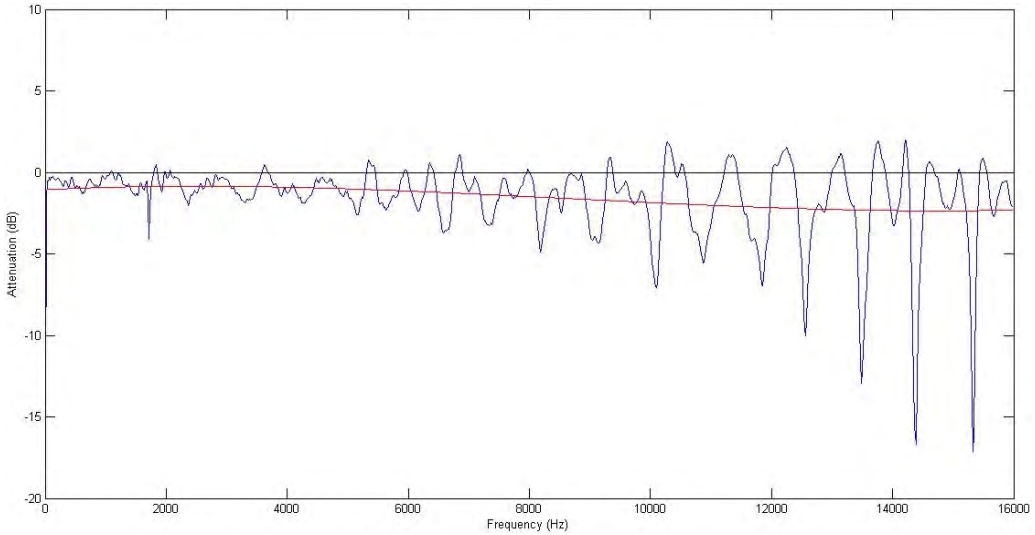

Fig. 3.62: Attenuation for screen Enlightor 4K at a distance of 15 cm, 0 degrees.

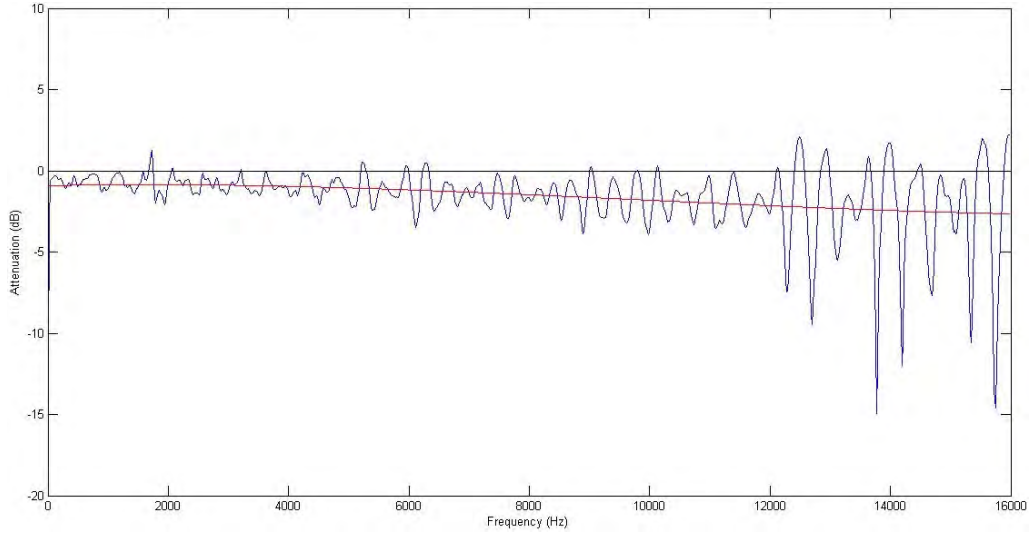

Fig. 3.63: Attenuation for screen Enlightor 4K at a distance of 30 cm, 0 degrees.

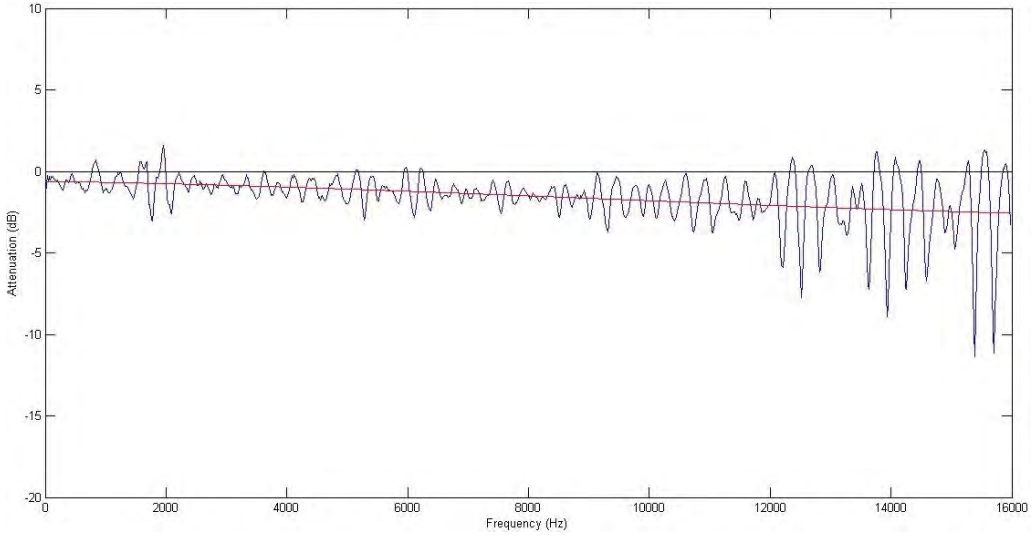

Fig. 3.64: Attenuation for screen Enlightor 4K at a distance of 45 cm, 0 degrees.

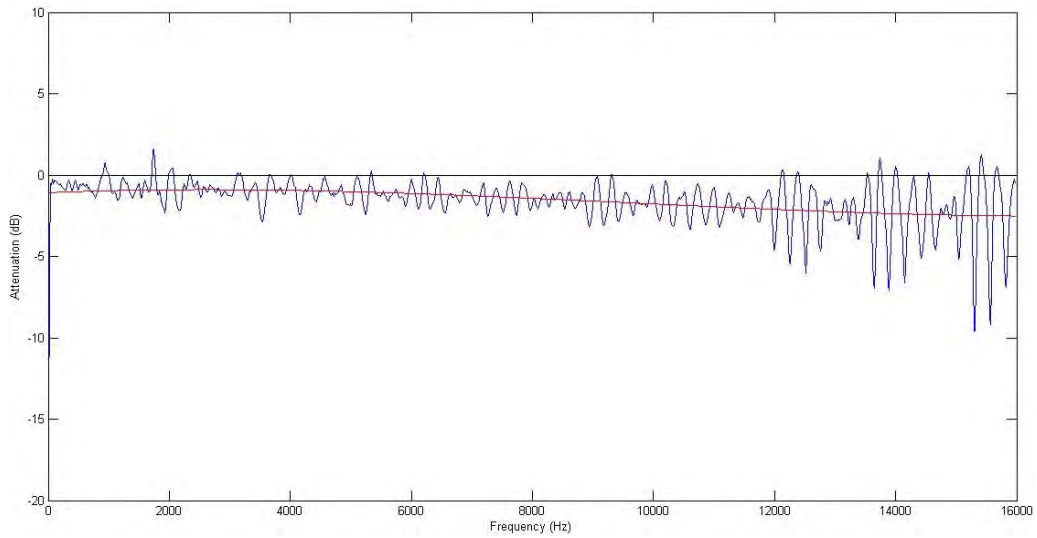

Fig. 3.65: Attenuation for screen Enlightor 4K at a distance of 60 cm, 0 degrees.

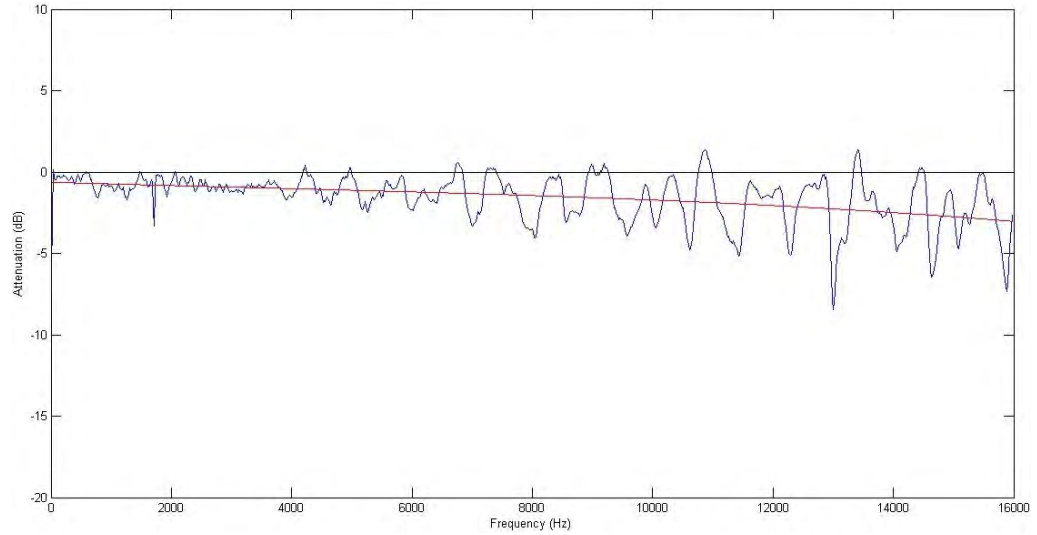

Fig. 3.66: Attenuation for screen Enlightor 4K with screen angled 10 degrees. Mic position 0 degrees.

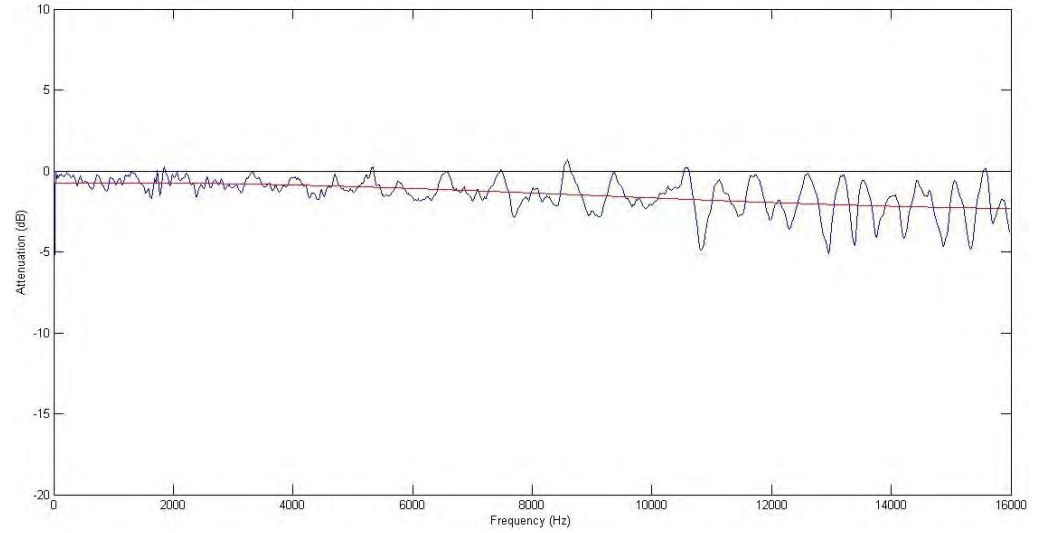

Fig. 3.67: Attenuation for screen Enlightor 4K with screen angled 25 degrees. Mic position 0 degrees.

The red line represents the tendency of the attenuation and the blue line the actual attenuation at that frequency. So at 16 kHz the attenuation is close to 2.5 dB which is the value given by Screen Excellence.

Although the attenuation that this screen introduces is very small, the distance at which the attenuation seems to be more stable at all frequencies is either 15 or 30 cm, with a small difference between low and high frequencies.

At 15 cm, the attenuation value obtained at 2 kHz is -0.72 dB and at 16 kHz is -2.31 dB, which means a difference of 1.6 dB; and at 30 cm, the attenuation value obtained at 2 kHz is -0.68 dB and at 16 kHz is -1.71 dB, leading to a difference in attenuation of 1 dB; which are considered to be very acceptable values.

Attenuation for screen Matt Plus MiniPerforated

As it can be seen in Fig. 3.68 (below), Harkness Screens claims the loss produced by the screen varies with the frequency, finding at 5 kHz an attenuation of 5dB and from there onwards with a major drop up to close to 14 dB at 16 kHz. However, no paper related to the installation of screen surfaces provided by Harkness Screens explains at which distance from the loudspeaker were screens mounted to take these measurements.[10]

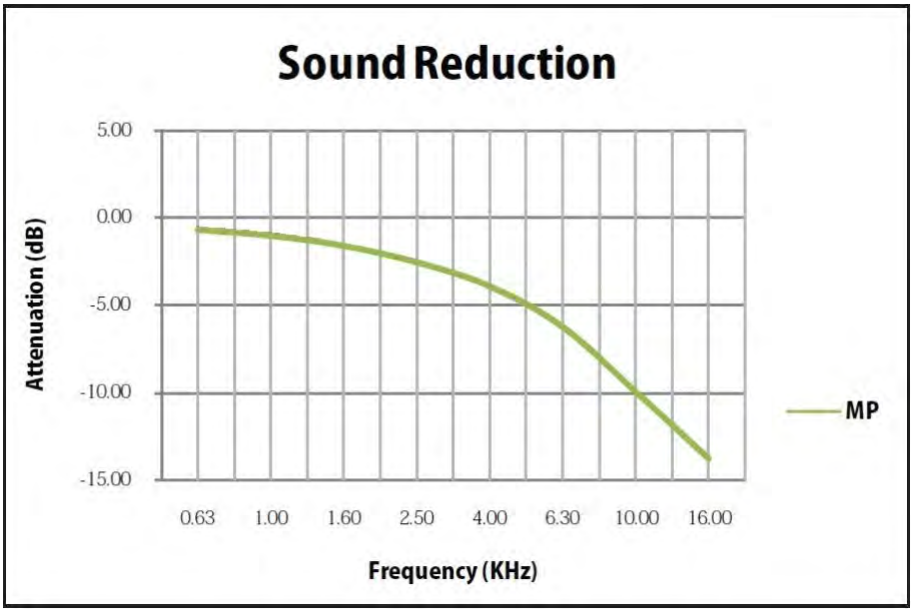

Fig. 3.68: Sound reduction for screen Matt Plus MiniPerforated by Harkness Screens

In the following figures it can be observed the attenuation variation in function of the distance from the screen sheet to the loudspeaker. Results obtained were relatively similar to the graph by Harkness Screens up to a 15 cm distance. Whereas, for a 30 cm distance and further and with the screen angled 10 and 25 degrees, attenuation dropped in all frequencies with an enormous speed, almost following a linear function.

Table 2: Attenuation measured at different distances for different frequencies, Matt Plus Miniperforated

Distance	Attenuation (dB) at 5 kHz	Attenuation (dB) at 10 kHz	Attenuation (dB) at 16 kHz
2 cm	-2,53	-5,50	-10,04
7 cm	-3,21	-6,57	-9,44
15 cm	-2,86	-7,17	-9,17
30 cm	-4,27	-8,01	-11,94
45 cm	-4,34	-8,30	-11,86
60 cm	-4,40	-8,40	-11,34
10 deg	-3,87	-7,04	-11,64
25 deg	-3,93	-7,40	-13,52

In Table 2, one can see that the attenuation provided by Harkness Screens could be for a distance between 30 and 60 cm. However, cepstrum analysis will be necessary to decide at which distance less late arrivals are found at the microphone position.

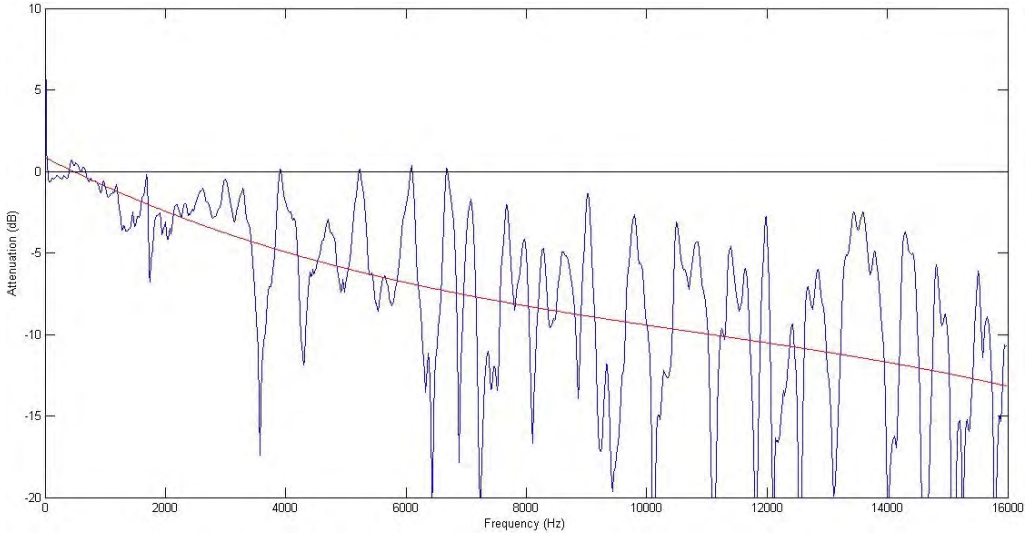

Fig. 3.69: Attenuation for screen Matt Plus Miniperforated at a distance of 2 cm, 0 degrees.

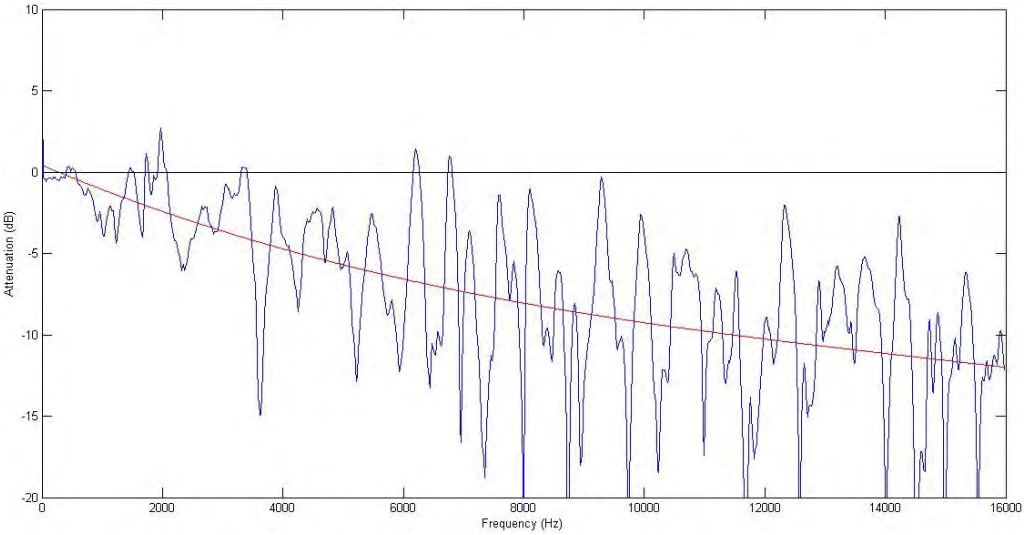

Fig. 3.70: Attenuation for screen Matt Plus Miniperforated at a distance of 7 cm, 0 degrees.

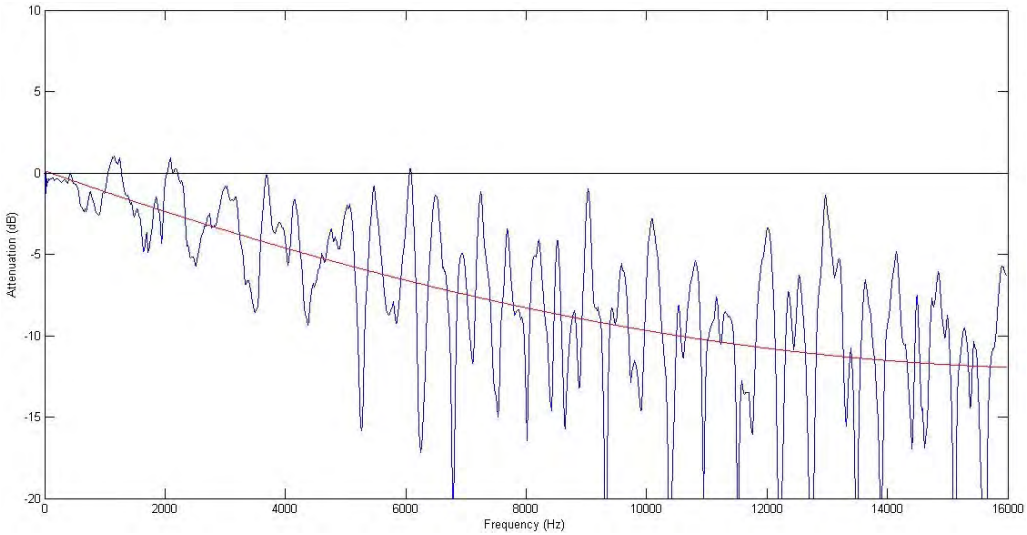

Fig. 3.71: Attenuation for screen Matt Plus Miniperforated at a distance of 15 cm, 0 degrees.

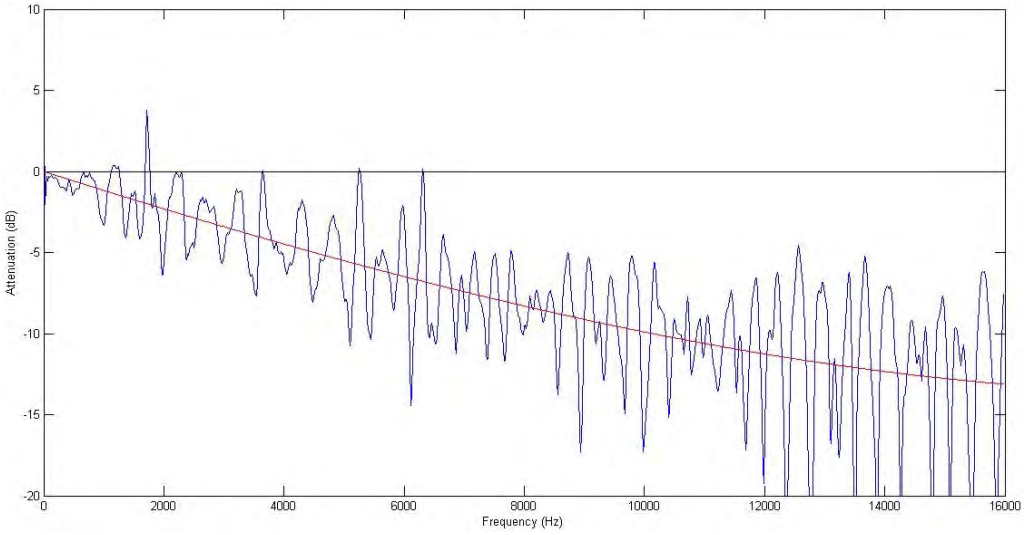

Fig. 3.72: Attenuation for screen Matt Plus Miniperforated at a distance of 30 cm, 0 degrees.

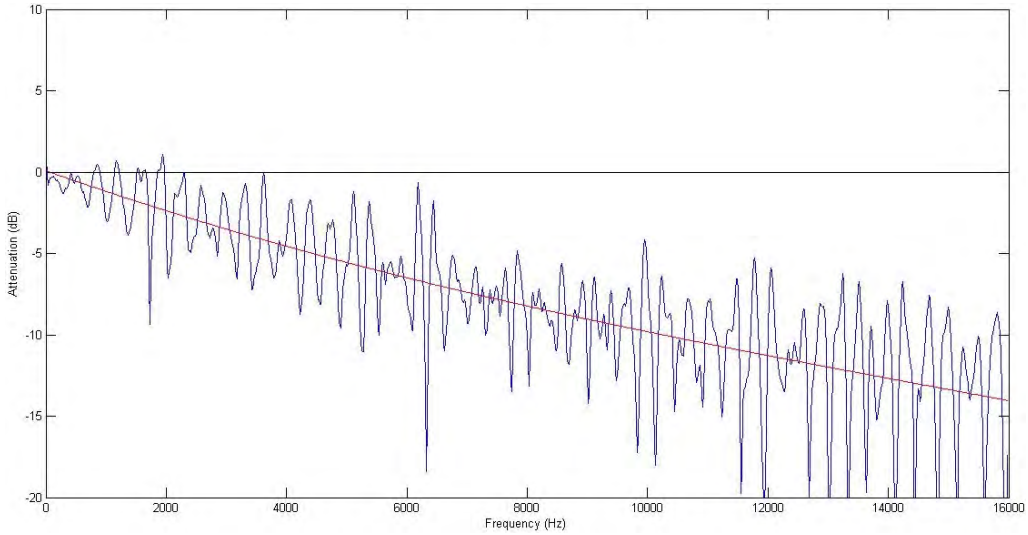

Fig. 3.73: Attenuation for screen Matt Plus Miniperforated at a distance of 45 cm, 0 degrees.

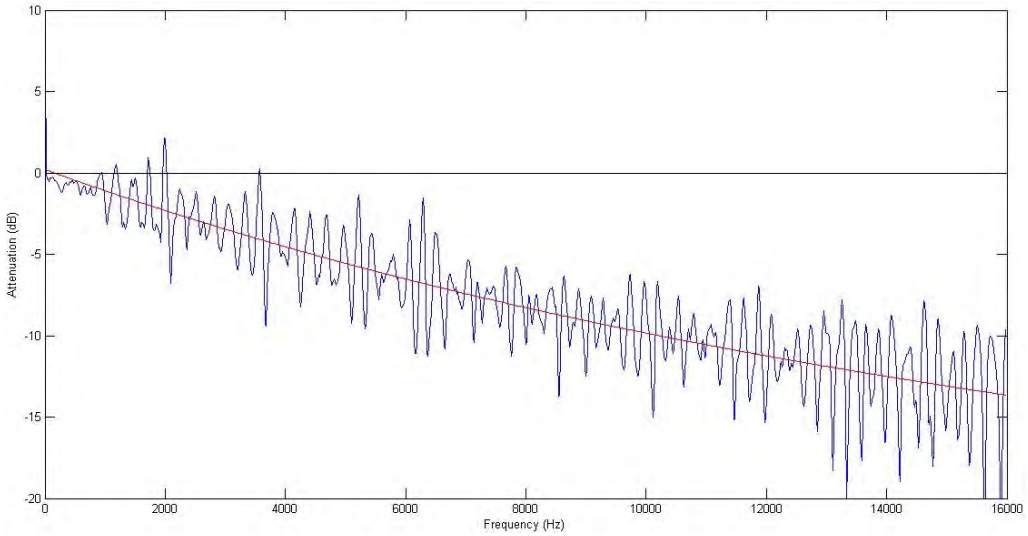

Fig. 3.74: Attenuation for screen Matt Plus Miniperforated at a distance of 60 cm, 0 degrees.

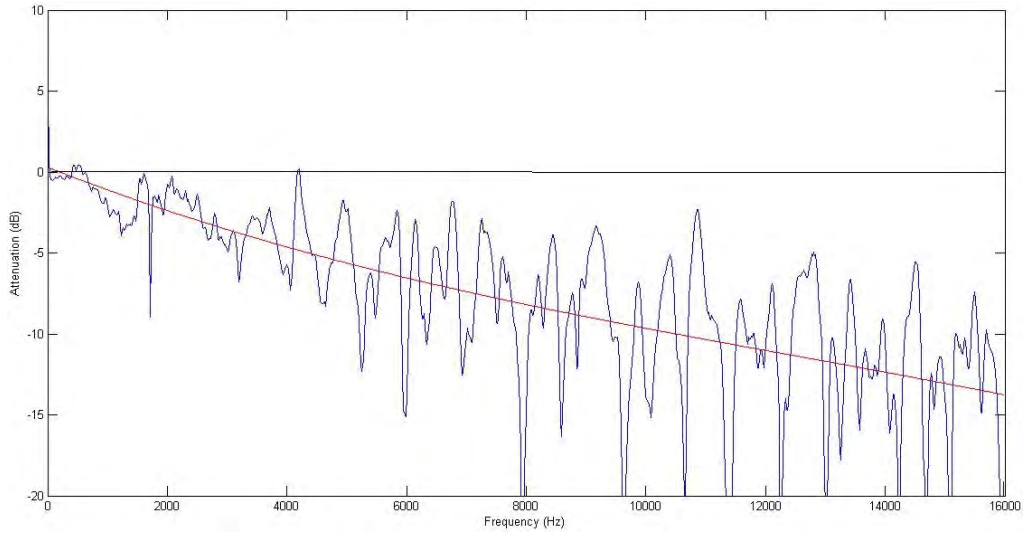

Fig. 3.75: Attenuation for Matt Plus Miniperforated with screen angled 10 degrees. Mic position 0 degrees.

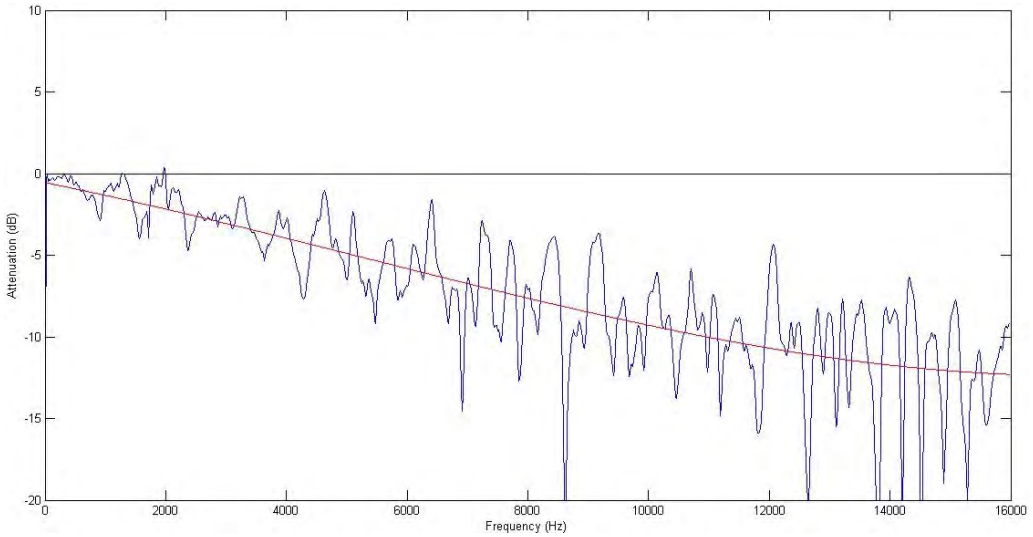

Fig. 3.76: Attenuation for Matt Plus Miniperforated with screen angled 25 degrees. Mic position 0 degrees.

Attenuation for screen ClearPix 2 White 1.0

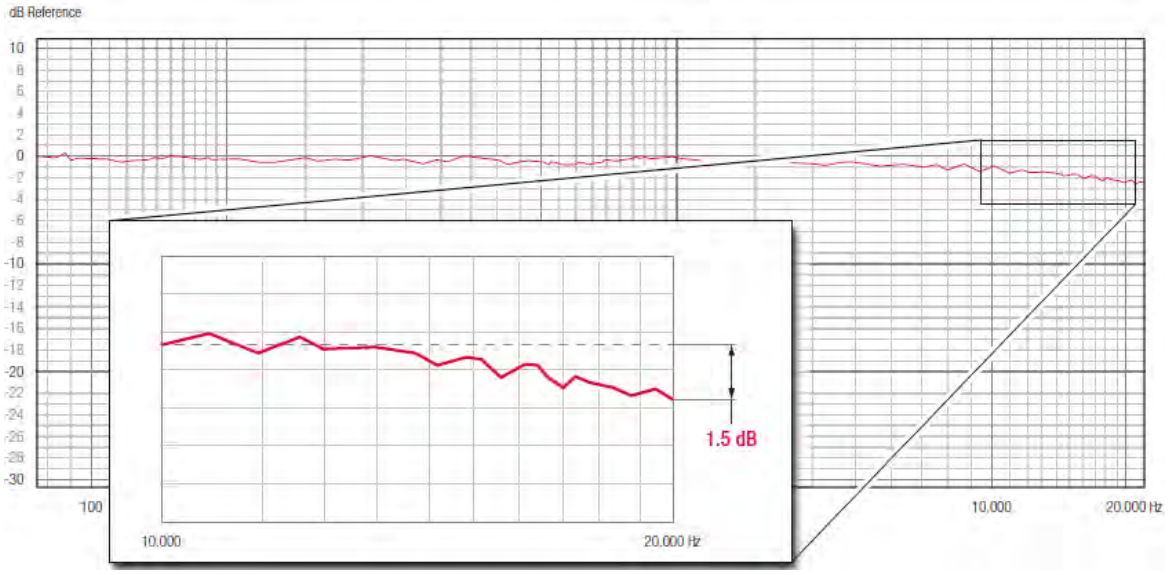

Fig. 3.77: Attenuation for screen ClearPix 2 White 1.0, by Screen Research

As it can be observed in the following table, the difference measured in attenuation obtained at high frequencies tends to be greater than praised by Screen Research, although at certain distances is very close to the value given by them it should borne in mind that their calculations go from 10 kHz to 20 kHz whereas ours go up to 16 kHz, which means that this difference could be even greater.

Table 3: Measured attenuation difference at high frequencies for screen ClearPix 2 White1.0

Distance (cm)	Attenuation difference (dB) (10 kHz-16 kHz)
2	2,6
7	1,9
15	1,7
30	1,9
45	1,8
60	2,0

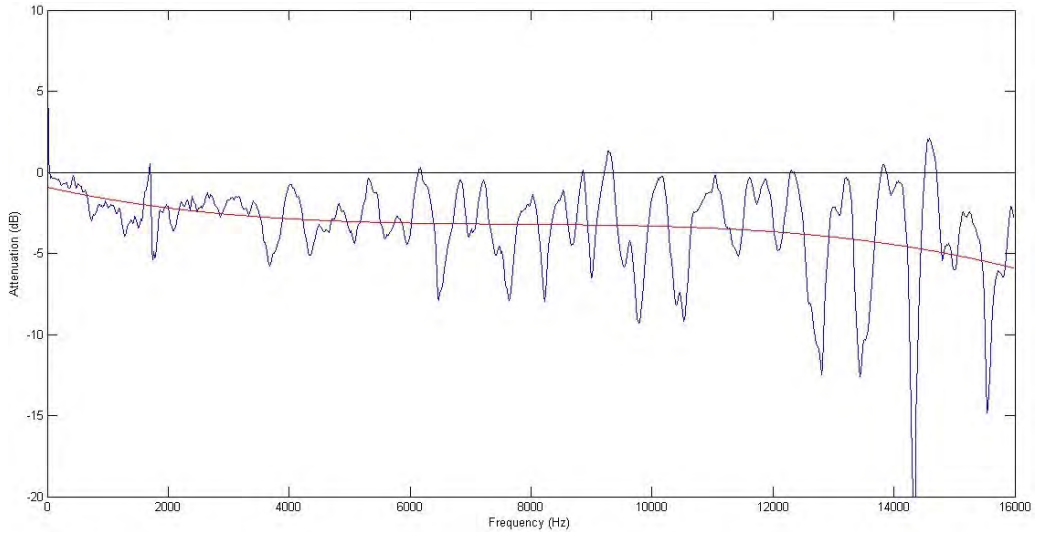

Fig. 3.78: Attenuation for screen ClearPix 2 White 1.0 at a distance of 2 cm, 0 degrees.

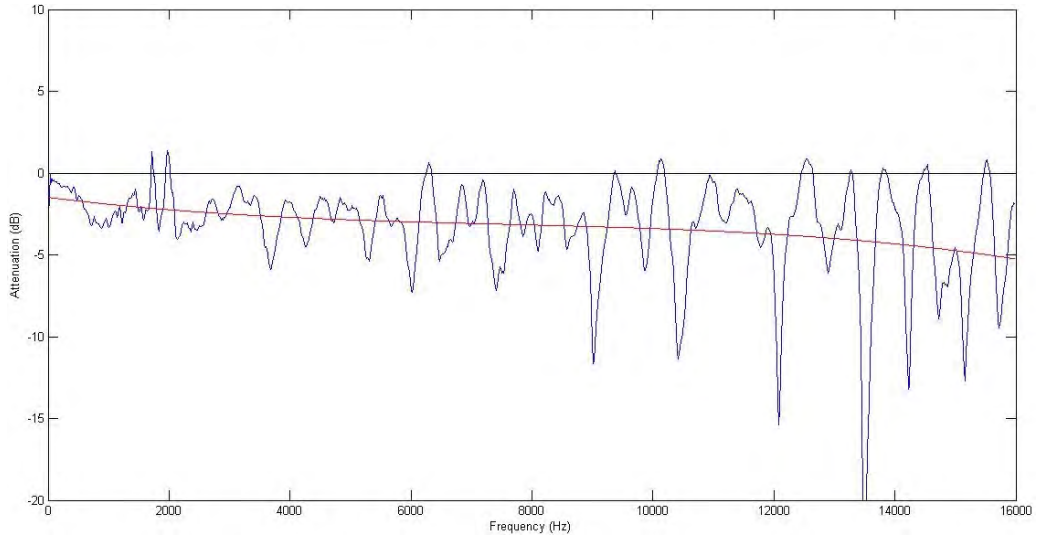

Fig. 3.79: Attenuation for screen ClearPix 2 White 1.0 at a distance of 7 cm, 0 degrees.

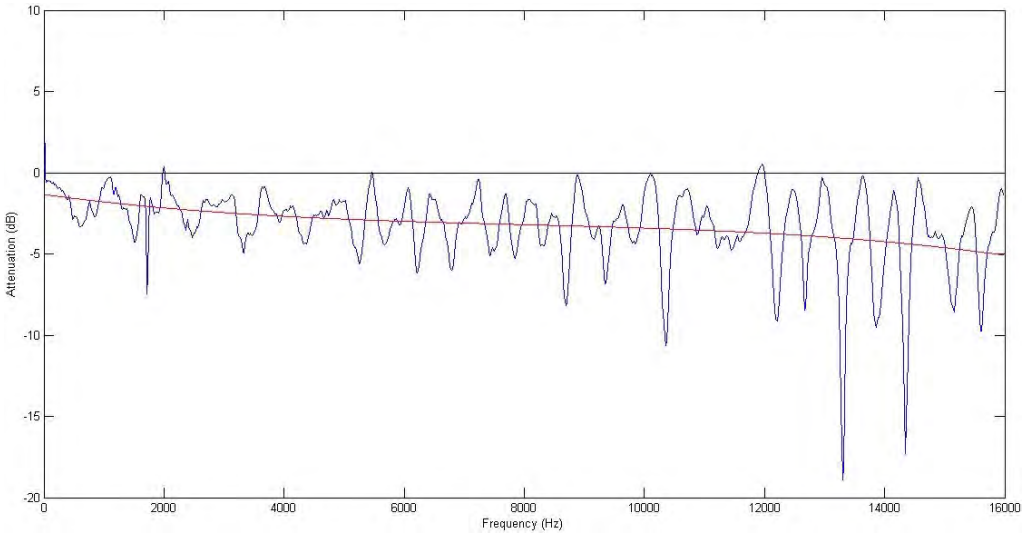

Fig. 3.80: Attenuation for screen ClearPix 2 White 1.0 at a distance of 15 cm, 0 degrees.

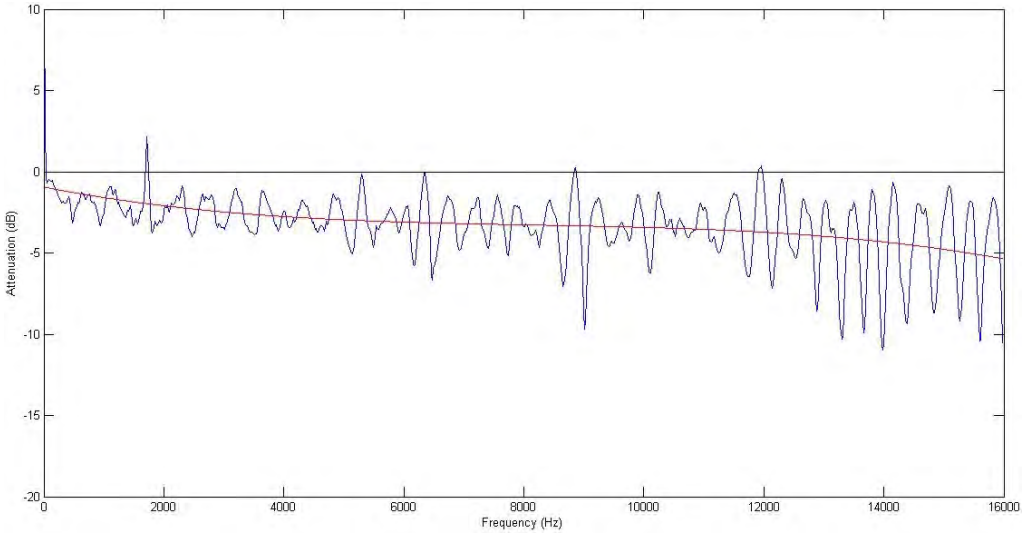

Fig. 3.81: Attenuation for screen ClearPix 2 White 1.0 at a distance of 30 cm, 0 degrees.

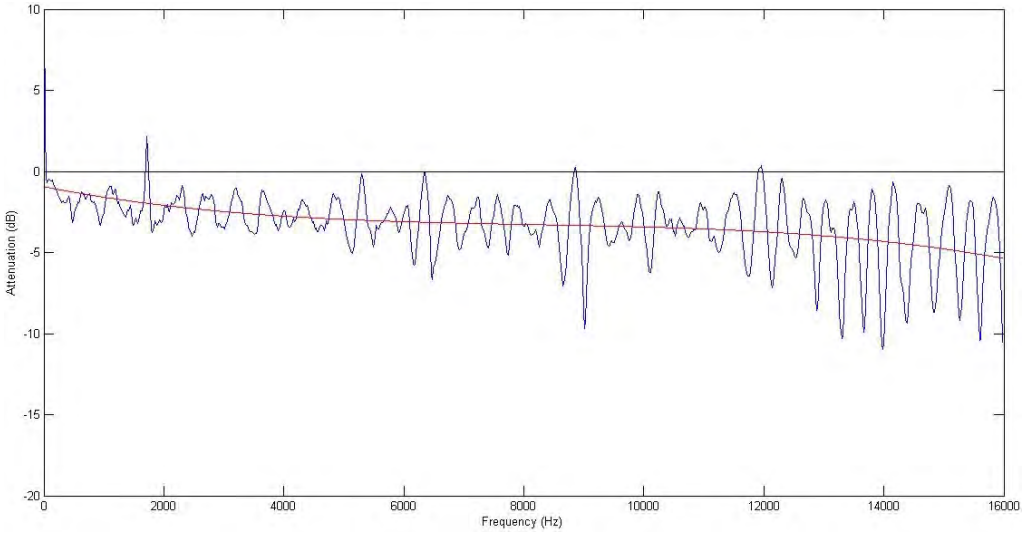

Fig. 3.82: Attenuation for screen ClearPix 2 White 1.0 at a distance of 45 cm, 0 degrees.

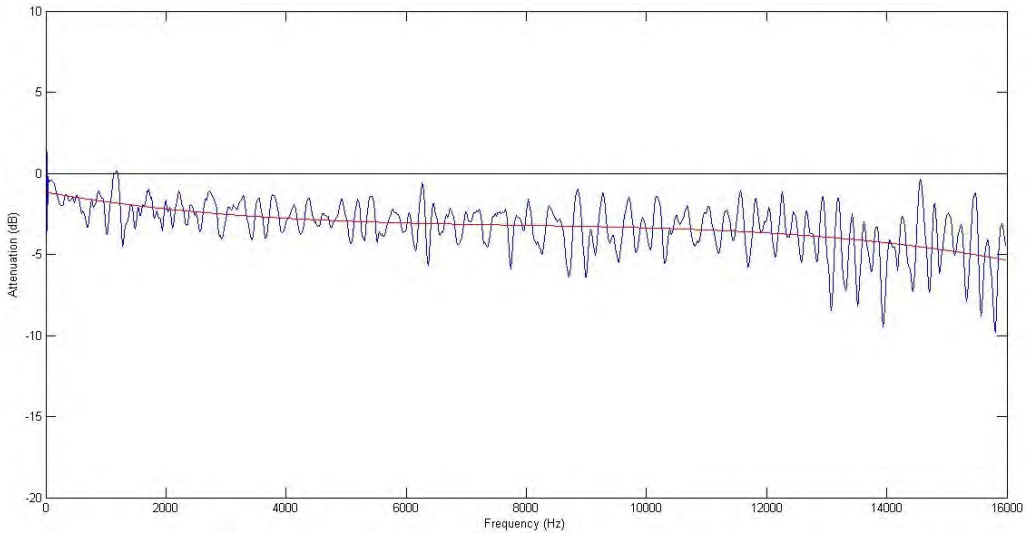

Fig. 3.83: Attenuation for screen ClearPix 2 White 1.0 at a distance of 60 cm, 0 degrees.

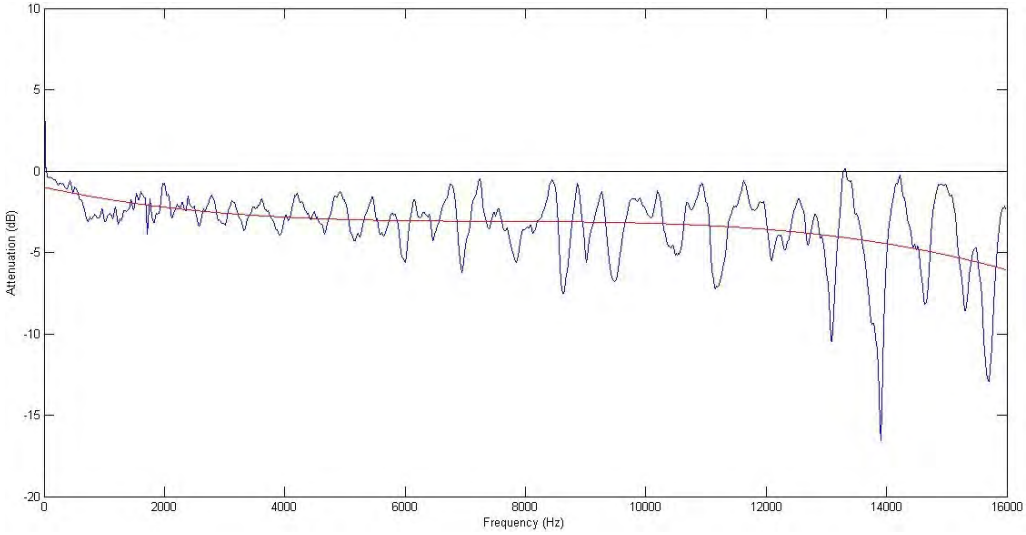

Fig. 3.84 Attenuation for ClearPix 2 White 1.0 with screen angled 10 degrees. Mic position 0 deg.

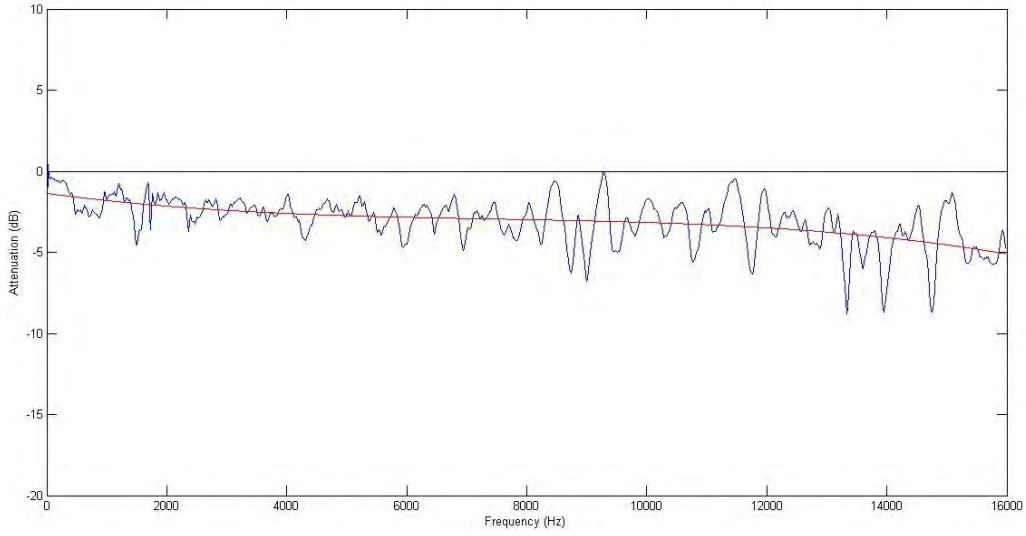

Fig. 3.85: Attenuation for ClearPix 2 White 1.0 with screen angled 25 degrees. Mic position 0 deg.

3.5. Cepstrum

Theoretically, by simply bearing in mind the added path that the sound wave has to cover (double of the distance from the loudspeaker to the screen) when it travels forward and backwards in between the loudspeaker and the screen sheet, and equation (3.6), knowing which delay may appear is of great facility

$$t = \frac{x}{c} \quad \text{(s)}, \tag{3.6}$$

where x is the distance from the loudspeaker to the screen expressed in meters and c is the sound speed (343 m/s)

By performing a cepstrum analysis on the data collected, the difference between later arrivals and the direct sound wave at the microphone was discovered and found a common caption at all cases which could be a floor reflection. This caption was always found around 1.6 ms which coincided with a pos sible reflection at half of the path if theoretically calculated.

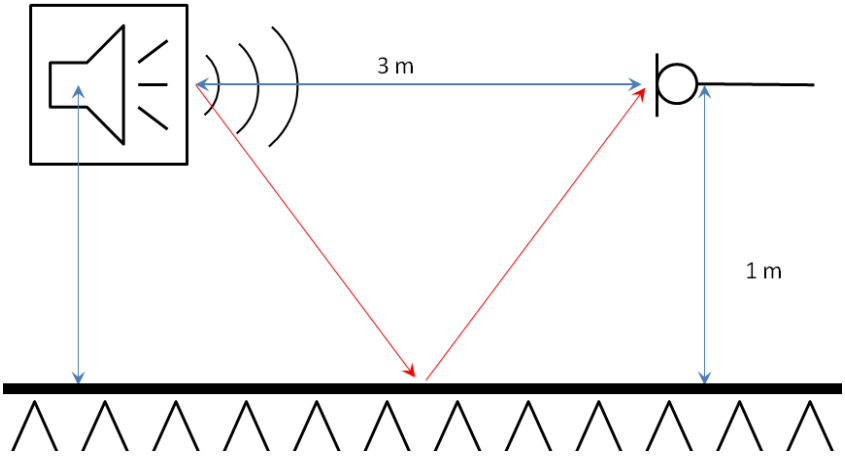

Fig. 3.86: Sketch of sound wave reflection on the floor at half of the path

Theoretically, placing the screens at a distance of 2 cm from the loudspeaker can cause a first delay at 0.12 ms and a second delay at 0.23 ms, plus the floor reflection.

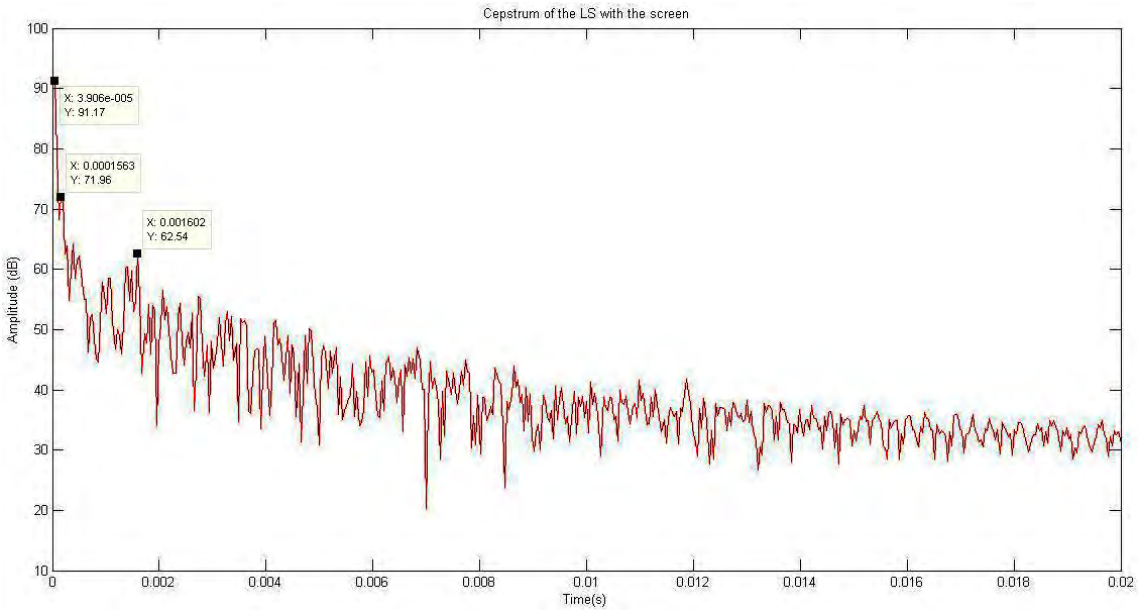

Fig. 3.87: Cepstrum for Enlightor 4K at 2 cm, 0 degrees.

As it can be seen in Fig. 3.87, with Enlightor 4K screen the first late arrival is found at 0.156 ms later than the direct signal with an amplitude difference of 19.2 dB and the floor reflection is at 1.6 ms, arriving with 28.6 dB less strength than the direct wave.

Fig. 3.88 shows the cepstrum for screen Matt Plus MiniPerforated, where a first late arrival is found at 0.156 ms with a 22.1 dB difference in level than the direct wave. However, apart from this late arrival and the floor reflection which occurs 1.6 ms later as expected, there are other late arrivals of significant amplitude that could cause comb filtering and happen for reasons unknown. They could be sound waves which instead of going through the screen could have taken a flanking path surrounding the screen and not following a precise pattern.

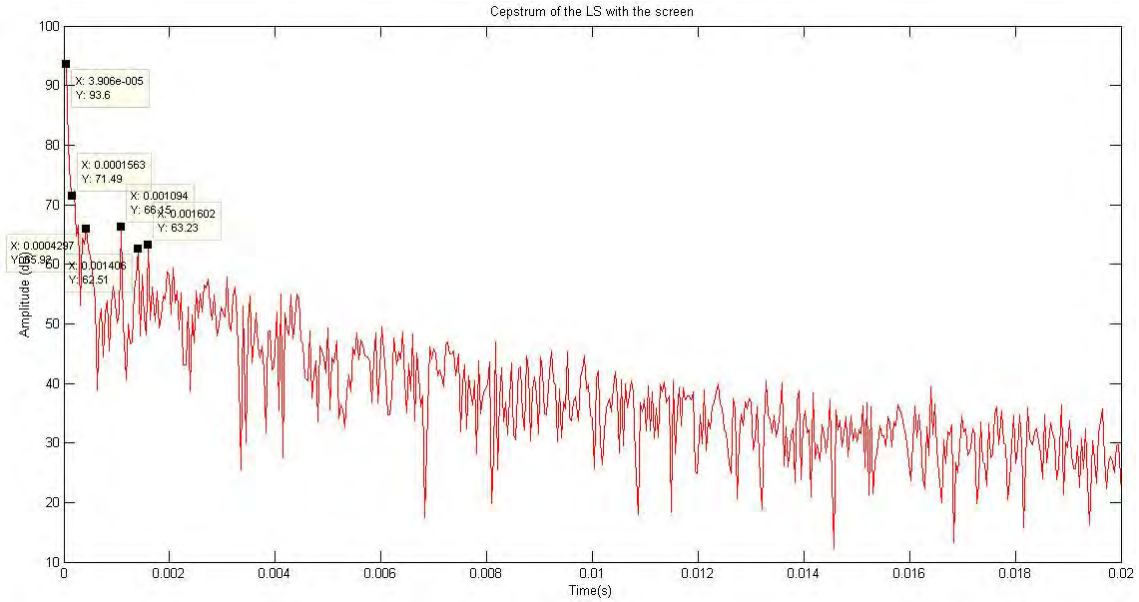

Fig. 3.88: Cepstrum for Matt Plus Miniperforated at 2 cm, 0 degrees.

In Fig. 3.89 can be seen how the 0.156 ms delay repeats as expected with a 20 dB less amplitude than the direct wave. However, the floor reflection now seems to be at 1.9 ms and a later arrival which theoretically could happen at 0.35 ms appears to be noticeable at 0.39 ms with 24.7 dB less amplitude than the direct signal. As well as in screen Matt Plus MiniPerforated, some other late arrivals which could be associated to flanking paths occur.

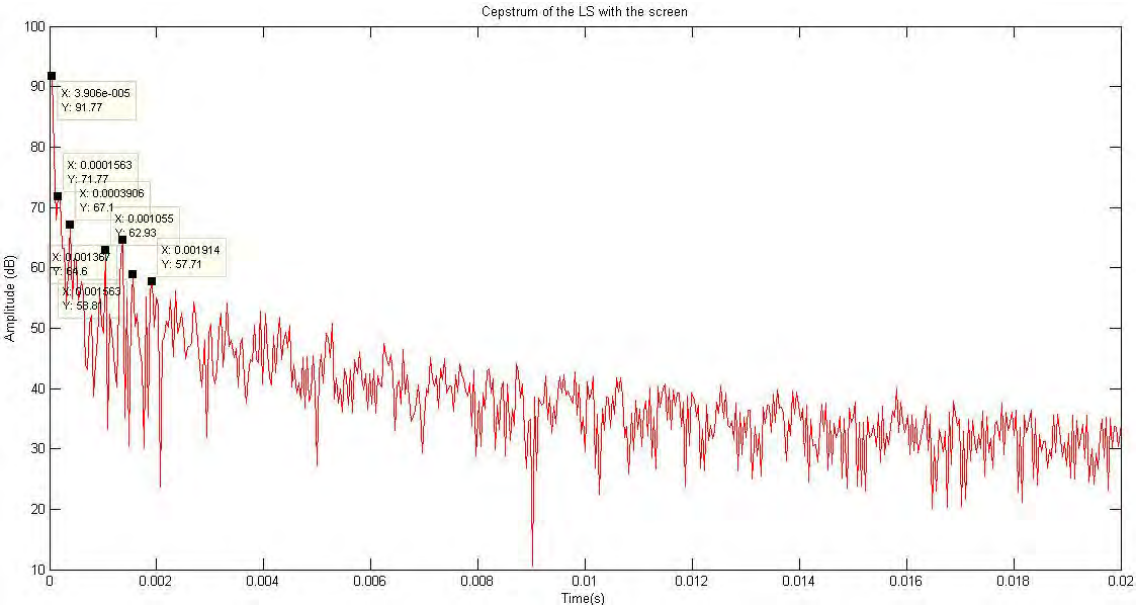

Fig. 3.89: Cepstrum for ClearPix 2 White 1.0 at 2 cm, 0 degrees.

When the screens are placed at a distance of 7 cm from the loudspeaker, the first late arrival should happen at 0.41 ms and the second one at 0.82 ms.

In the following figures it can be seen how it varies from one screen to another.

In the three cases, the floor reflection remains at 1.6 ms with an attenuation of 28.4 dB, 29.8 dB and 30.5 dB respectively; and the first late arrival occurs at 0.39 which is an acceptable value. Second late arrival varies a bit more with different screens. When using Enlightor 4K the second late arrival is at 0.93 ms, whereas with Matt Plus MiniPerforated there is an arrival at 0.7 ms. However, with ClearPix 2 White 1.0 the second late arrival is of little relevance as its amplitude is not very high. Although, a third late arrival which should be received at the microphone position at 1.22 ms, is found at 1.36 ms.

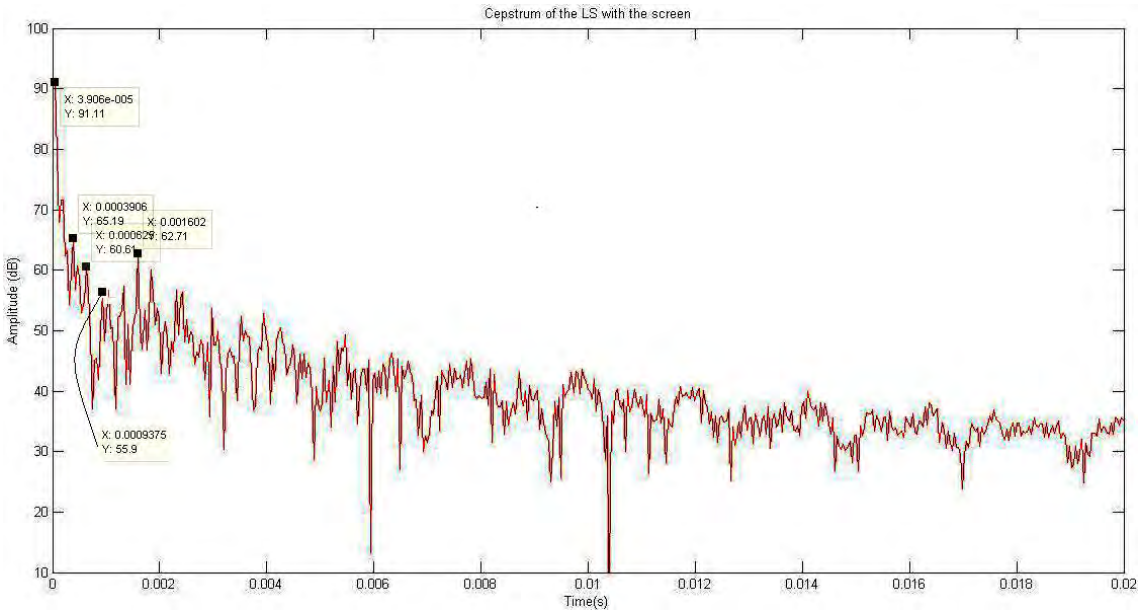

Fig. 3.90: Cepstrum for Enlightor 4K at 7 cm, 0 degrees.

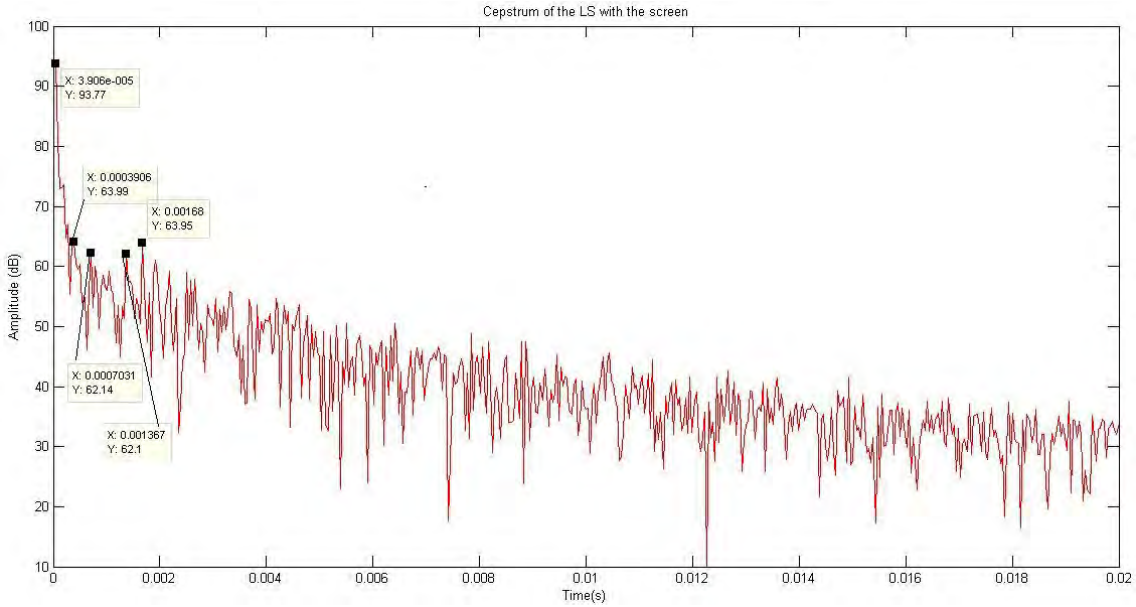

Fig. 3.91: Cepstrum for Matt Plus Miniperforated at 7 cm, 0 degrees.

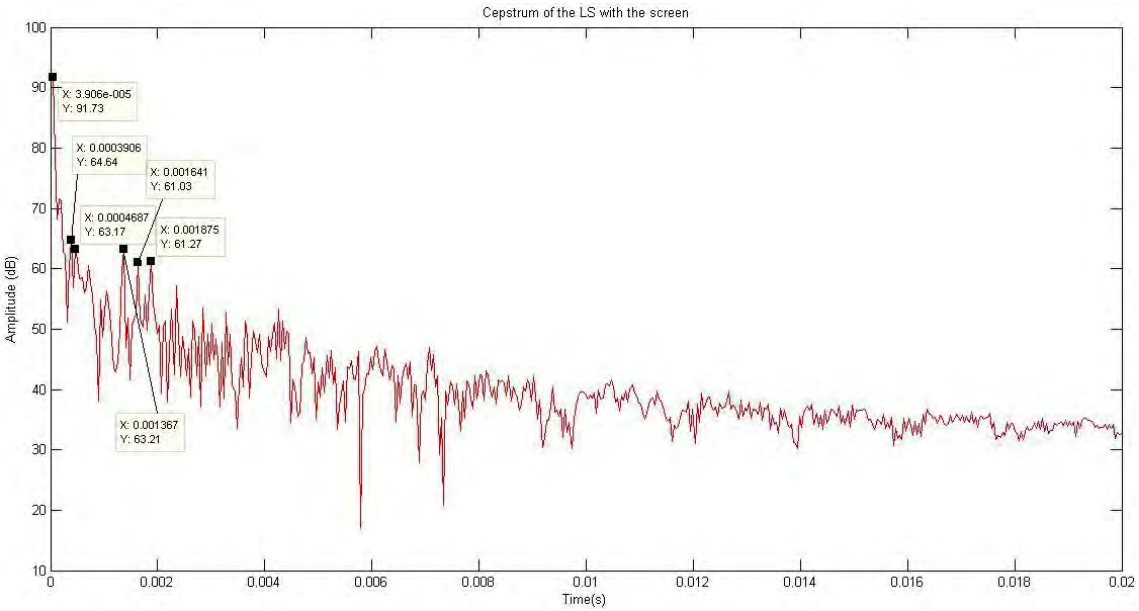

Fig. 3.92: Cepstrum for ClearPix 2 White 1.0 at 7 cm, 0 degrees.

At a distance of 15 cm between the loudspeaker and the screen, the first late arrival is meant to happen at 0.87 ms and the second one at 1.7 ms.

The floor reflection delay is common for the three screens and it is characterised to be of 1.758 ms later than the direct signal. This floor reflection arrives at the microphone at the same time as the second late arrival, which could lead to an increase of amplitude in the cepstrum analysis at this lapse of time, as they could be added together.

As Fig. 3.93 shows, with Enlightor 4K, the first arrival occurs at 0.93 ms, however, it is not very emphasised in comparison to the next delay, which occurs 1.11 ms later than the initial wave. Nevertheless, there is no certainty whether this is a late arrival which may have occurred by the covered path of the reflected wave between the loudspeaker and the screen or if it is caused by a sound wave taking a flanking path instead of going through the screen. The second late arrival coincides with the floor reflection at 1.7 ms, as theoretically expected. Finally, a third late arrival is supposed to appear 2.6 ms later than the direct sound wave and as it can be seen in the figure below it looks reasonable to be the arrival at 2.1 ms.

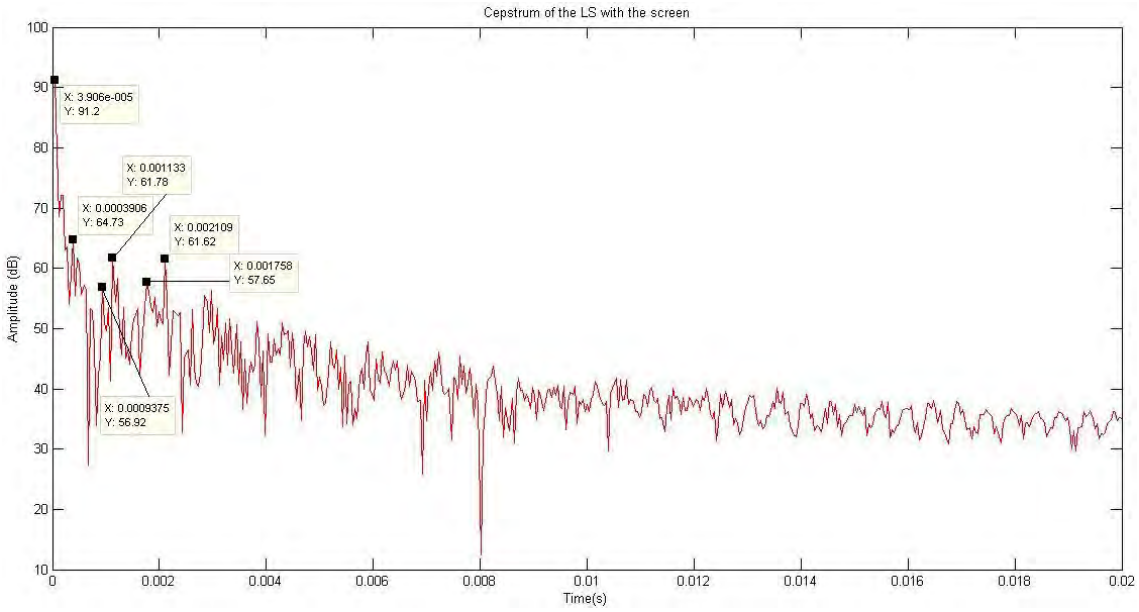

Fig. 3.94: Cepstrum for Enlightor 4K at 15 cm, 0 degrees.

In the next page, Fig. 3.95 shows that the only late arrivals which come to appear in the cepstrum are the first and second late arrivals caused by the covered path of the reflected wave

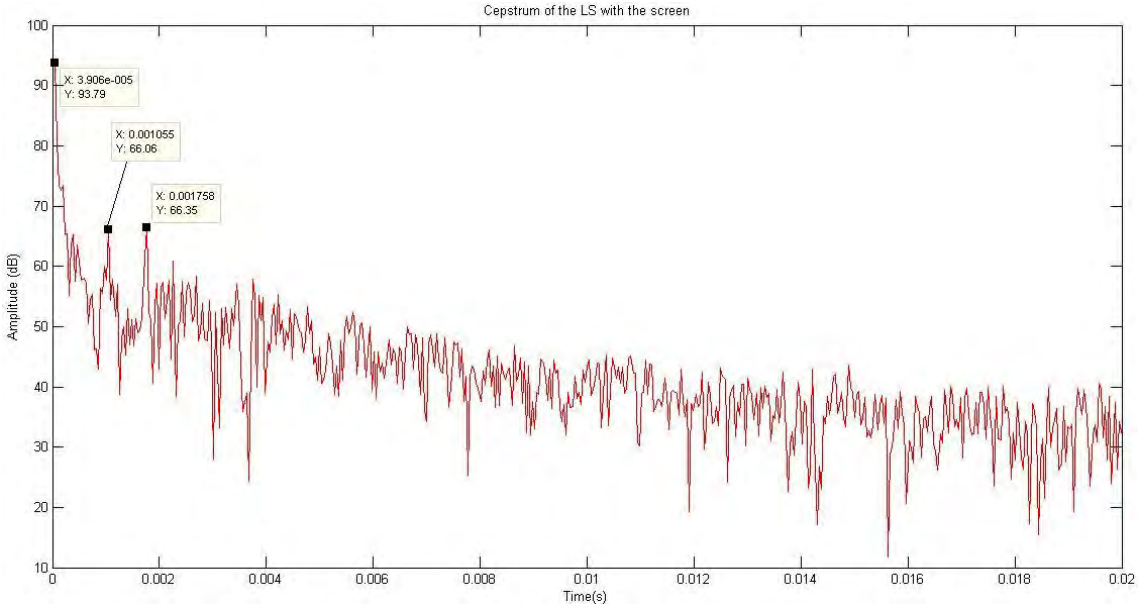

Fig. 3.95: Cepstrum for Matt Plus Miniperforated at 15 cm, 0 degrees.

In Fig. 3.96, apart from the 3 first late arrivals, there is a peak at 0.39 ms with an amplitude 5 dB above the first late arrival which occurs 1 ms later than the direct wave. This peak could be ignored as the delay time at which it occurs is very small in comparison to the late arrivals.

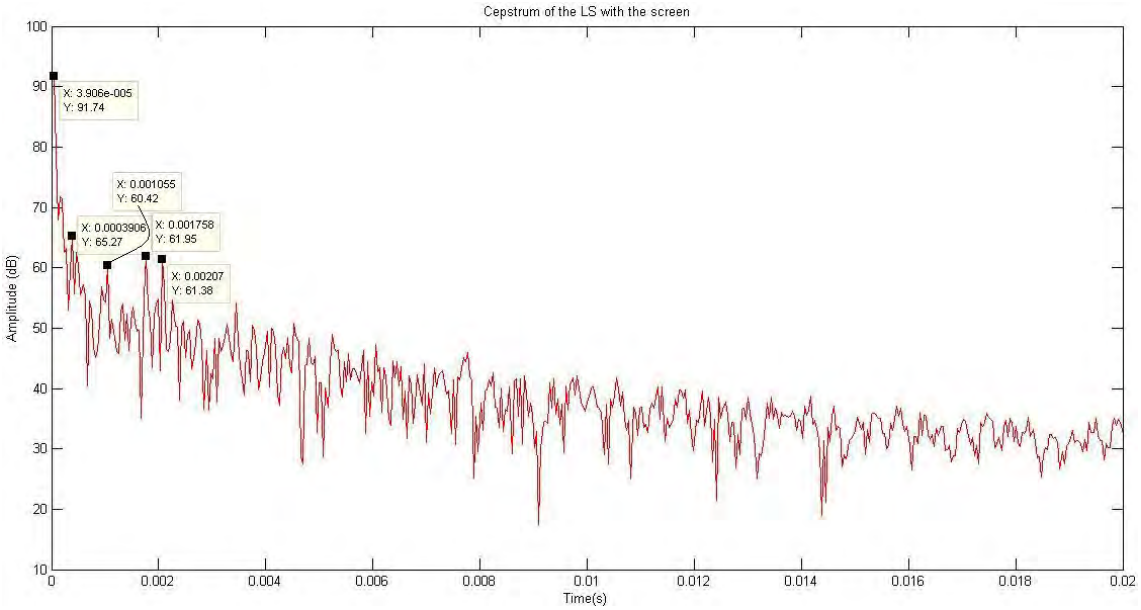

Fig. 3.96: Cepstrum for ClearPix 2 White 1.0 at 15 cm, 0 degrees.

When the distance is increased to 30 cm, the first late arrival should be found at 1.7 ms (coinciding with the floor reflection), the second one at 3.5 ms and the third one at 5.3 ms.

At this distance between the loudspeaker and the screen and according to cepstrum analysis, the floor reflection is now found a bit later than before appearing at 1.9 ms.

As it can be observed from Fig. 3.97 to Fig. 3.99, at this distance several late arrivals are captured by the microphone, increasing the number of them up to 5. Because of their up to 7 ms delay, they will probably cause comb filtering which could deteriorate the direct signal and worsening the sound quality in cinemas if the screen is placed at this distance

At the same time, it should be highlighted the fact that screen ClearPix 2 White 1.0 appears to be the one with the smaller number of backward reflections at this distance with a maximum number of 3, arriving this last one 5 ms later than the original sound wave.

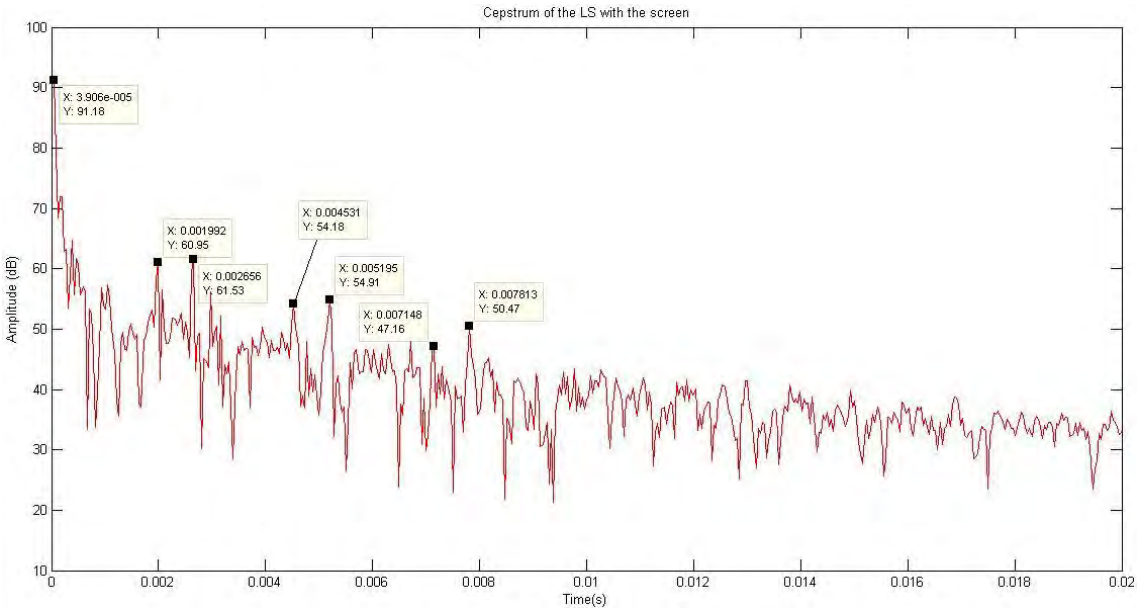

Fig. 3.97: Cepstrum for Enlightor 4K at 30 cm, 0 degrees.

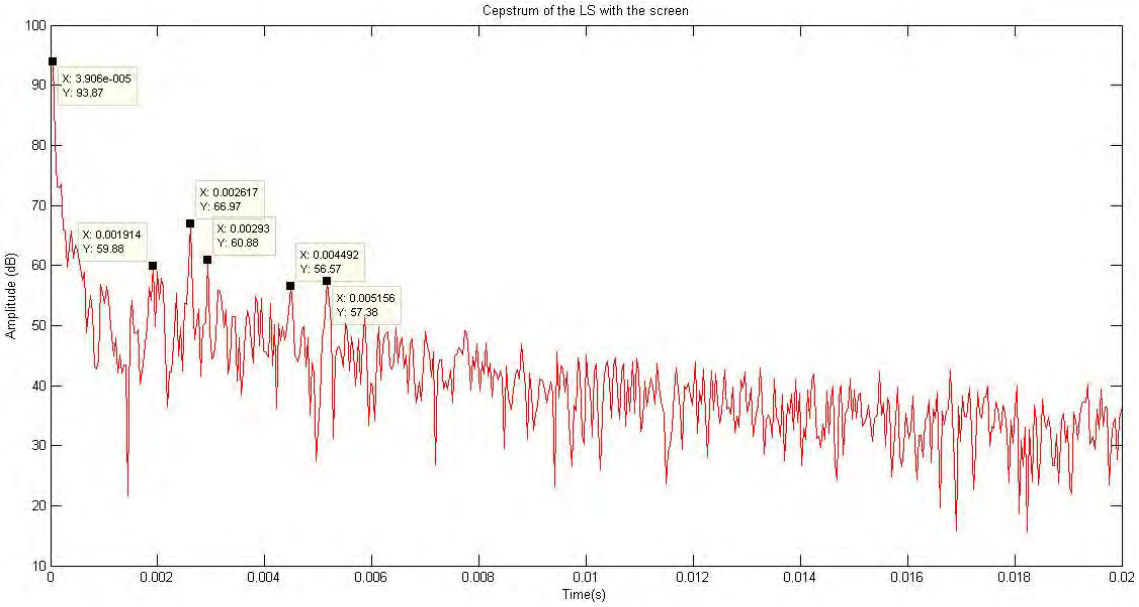

Fig. 3.98: Cepstrum for Matt Plus Miniperforated at 30 cm, 0 degrees.

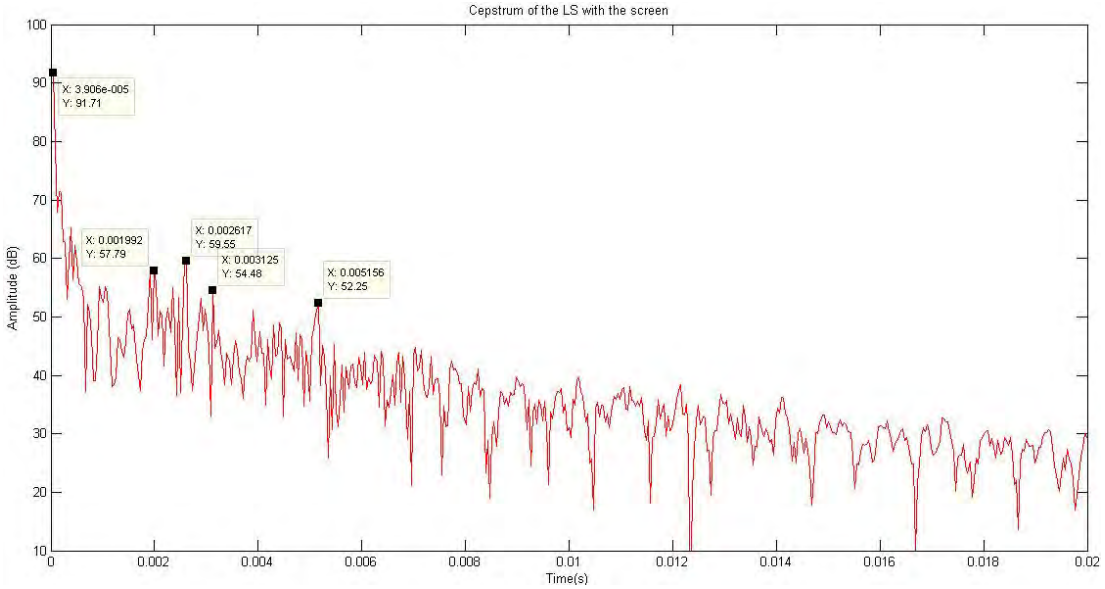

Fig. 3.99: Cepstrum for ClearPix 2 White 1.0 at 30 cm, 0 degrees.

Changing the distance to 45 cm, the fist arrival is expected at 2.6 ms and the second one at 5.2 ms, this means that the reflection on the floor should arrive firstly at the microphone than the waves which suffer the mirror effect.

Fig. 3.100 to Fig. 3.102 show how the floor reflection is hardly noticeable as the first reflected wave is of higher amplitude. As it has happened at previous analysed distances, some other delays which are not related to the screen reflection appear to be captured at the microphone position arriving with an approximate delay of 3.5 ms.

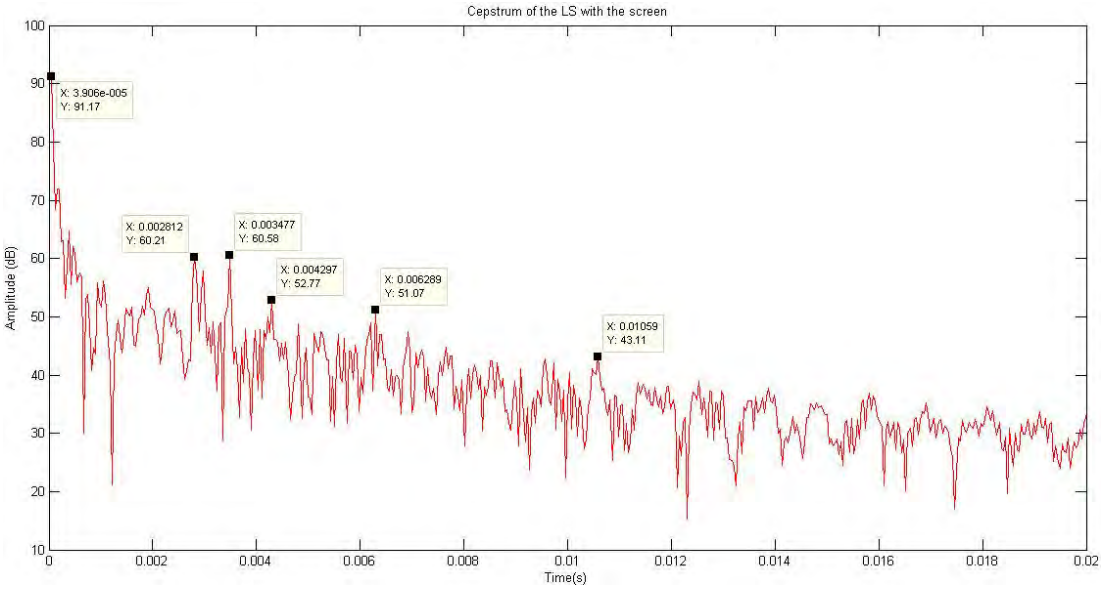

Fig. 3.100: Cepstrum for Enlightor 4K at 45 cm, 0 degrees.

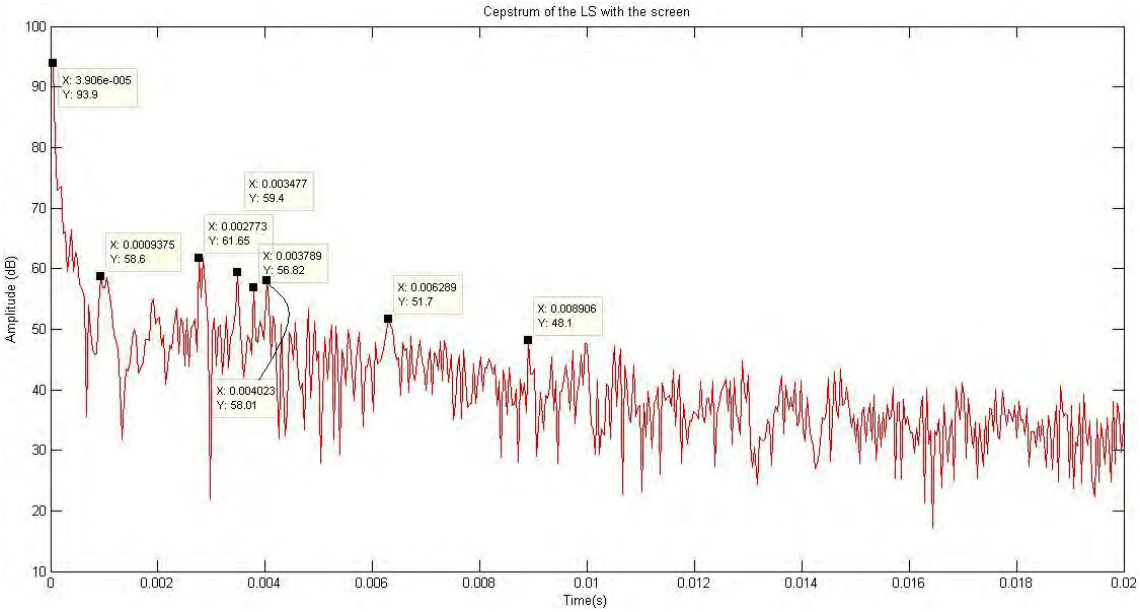

Fig. 3.101: Cepstrum for Matt Plus Miniperforated at 45 cm, 0 degrees.

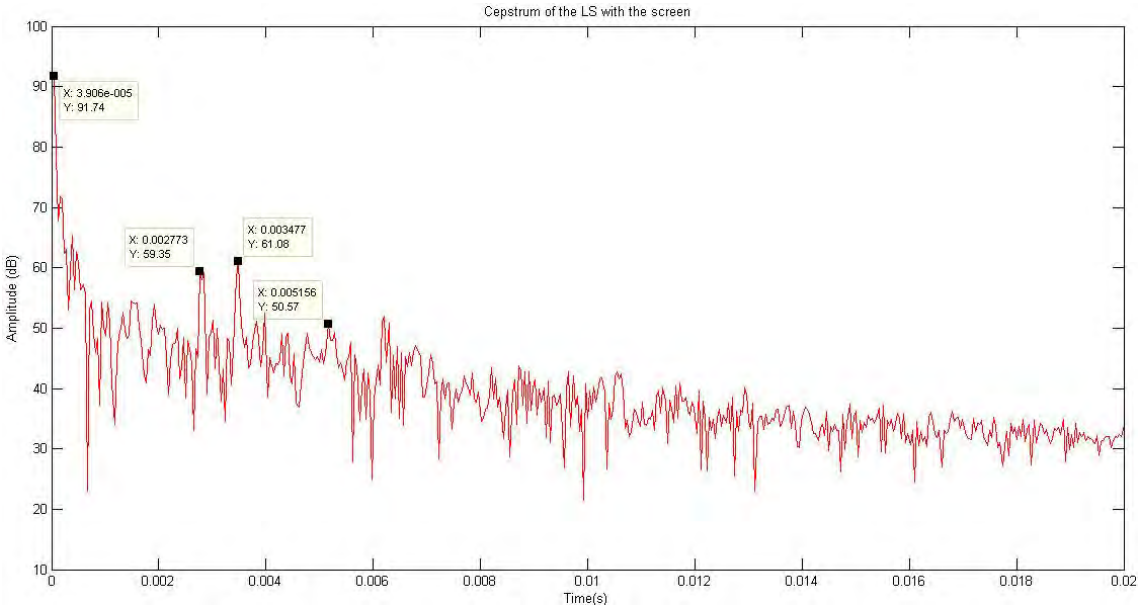

Fig. 3.102: Cepstrum for ClearPix 2 White 1.0 at 45 cm, 0 degrees.

If the distance between the loudspeaker and the screen is now increased to 60 cm the first late arrival is awaited at 3.5 ms and the second one at 7 ms.

For Enlightor 4K an unexpected late arrival appears 4.3 ms later than the original wave plus it is of higher amplitude than any other late arrival. Additionally to this, the first late arrival which occurs 3.6 ms later than the original sound wave would be one of the main causes for the comb filtering which is found at 60 cm distance as it was previously shown in Fig. 3.49 (Freq. response for screen Enlightor 4K at a distance of 60cm. 0 degrees).

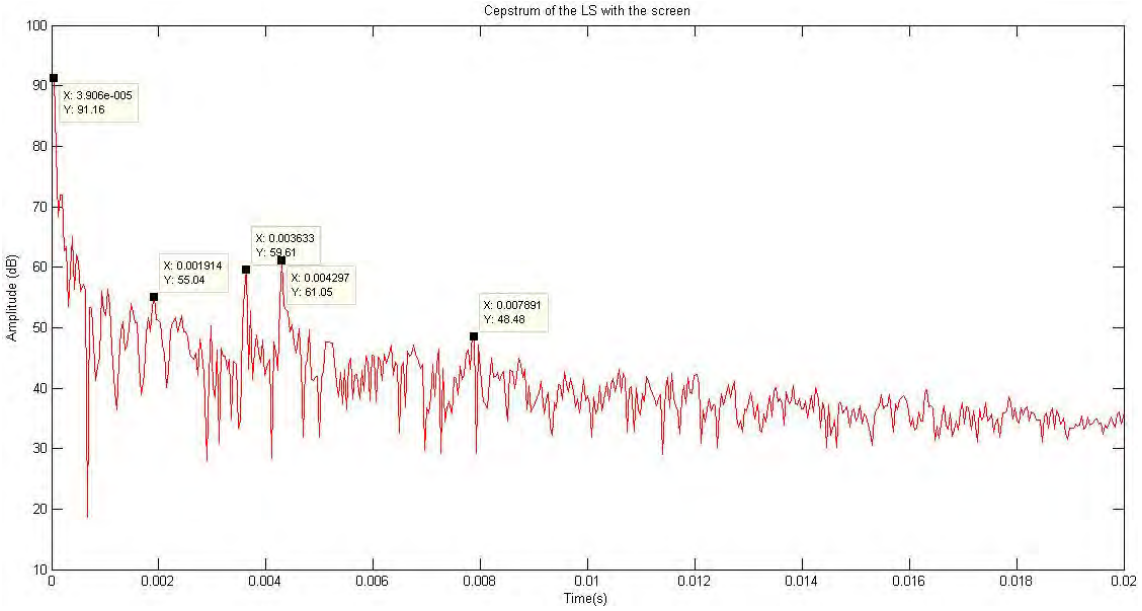

Fig. 3.103: Cepstrum for Enlightor 4K at 60 cm, 0 degrees

Cepstrum analysis for Matt Plus MiniPerforated at 60 cm shows various interesting peaks which are worth looking at. A third late arrival which theoretically should occur at 10 ms can be seen in the figure below happening around this expected time delay. This large amount of peaks could be one of the main causes of such an important comb filtering which appears in the frequency response.

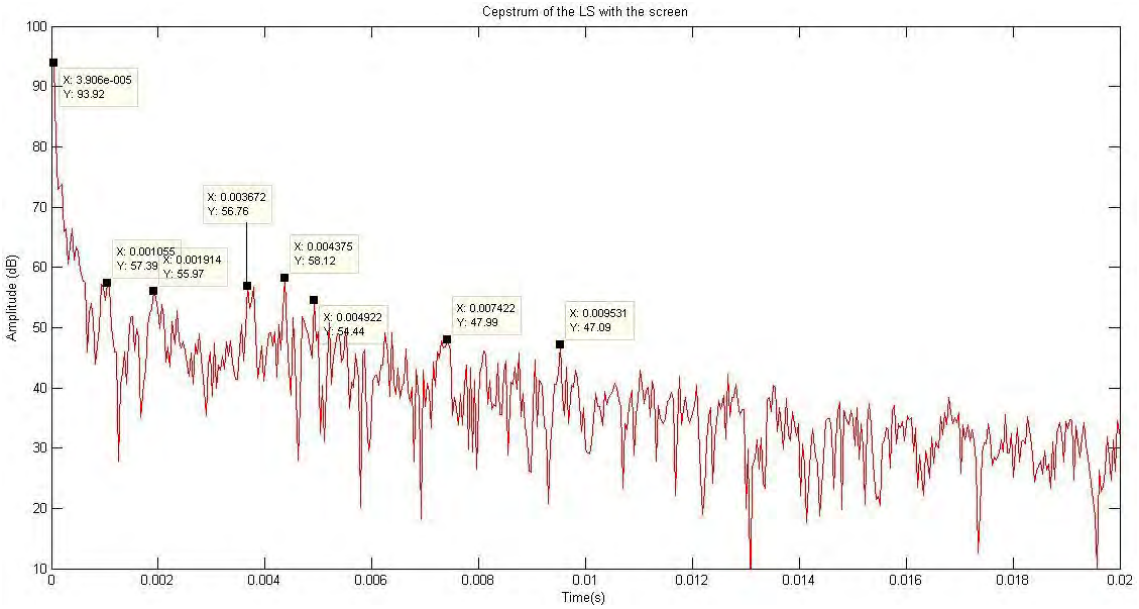

Fig. 3.104: Cepstrum for Matt Plus Miniperforated at 60 cm, 0 degrees.

However, at this distance, it looks more appropriate to use the screen ClearPix 2 White 1.0 as the floor reflection can barely be noticed and the second and third late arrival are of small amplitude. The only predictable late arrival would be the first one, happening at the microphone 4.44 ms later than the direct sound wave with a smaller amplitude than the original source, although if their amplitudes are added together the result (91.9 dB) is a bit higher than the original source, which leads to a certain knowledge that comb filtering is going to happen.

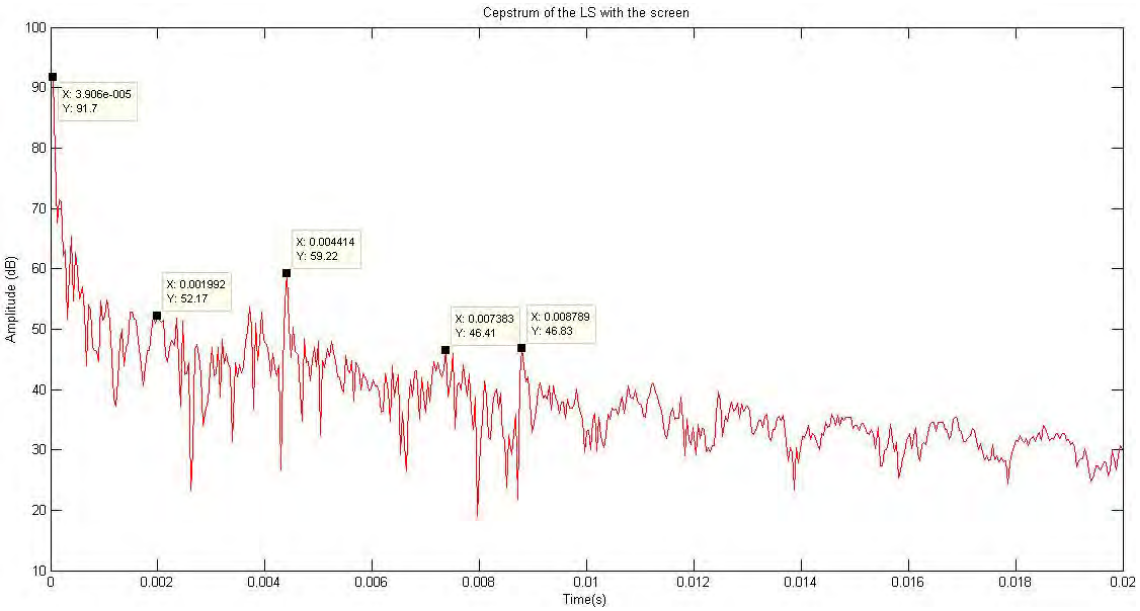

Fig. 3.105: Cepstrum for ClearPix 2 White 1.0 at 60 cm, 0 degrees.

4. Modelling

With the main goal of understanding the sound waves behaviour through cinema screens, it has been tried to model the loss found at different frequencies by using different theories.

We are going to focus on the perforated screen Matt Plus MiniPerforated, as its manufacturer provides a wide amount of information in data sheets and website.

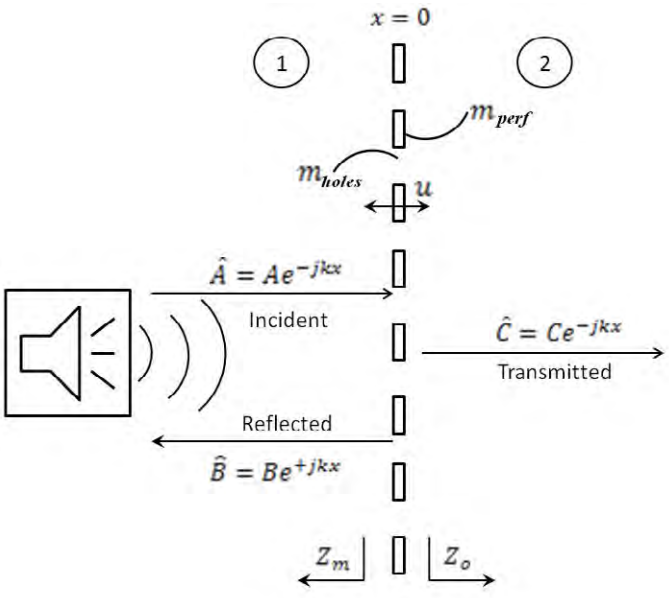

Fig. 4.1: Sketch of the transmitting sound wave process

.

Although the absorption is an important issue to bear in mind, manufacturers do not reveal the absorption coefficient that the material in which the screen is manufactured adds to the system, so in this model it is going to be considered that the incident energy which is not transmitted is reflected to the back ignoring the amount of it which is lost due to the absorption.

The mechanical impedance added by the screen is as follows,

$$\hat{Z}_m = \frac{\hat{F}}{\hat{u}} = j\omega m, \tag{4.1}$$

Where m is the mass per unit area of the screen.

The air impedance is

$$\hat{Z}_0 = \rho_o c_o = 415 \tag{4.2}$$

Where $\hat{F}$ is the force applied by the sound wave pressure coming from the loudspeaker, and $\hat{u}$ the velocity at which the sound particles are moved towards the screen, which it is directly related to the mechanical impedance added by the screen itself.

$$\hat{u} = \frac{\hat{F}}{\hat{Z}_m} \tag{4.3}$$

In 1, this force is equal to the sound pressure,

$$\hat{u} = \frac{\hat{p}}{j\omega m} \tag{4.4}$$

which at x= 0

$$\hat{p} = \hat{A} + \hat{B} - \hat{C} \tag{4.5}$$

Therefore

$$\hat{u} = \frac{\hat{A}+\hat{B}-\hat{C}}{j\omega m} = \frac{\hat{A}+\hat{B}-\hat{C}}{Z_m} \tag{4.6}$$

In 2, the velocity at which the air particles are moved is the relation between the sound pressure waves of the transmitted sound $\hat{C}$ over the air impedance.

$$\hat{u} = \frac{\hat{C}}{Z_o} \tag{4.7}$$

Substituting (4.7) in (4.6)

$$\frac{\hat{C}}{Z_o} = \frac{\hat{A}+\hat{B}-\hat{C}}{Z_m}, \tag{4.8}$$

and

$$\hat{B} = \hat{A} - \hat{C} \tag{4.9}$$

Therefore, transmission factor will be

$$\hat{T} = \frac{\hat{C}}{\hat{A}} = \frac{2 \cdot Z_o}{Z_m + 2 \cdot Z_o} \tag{4.10}$$

The loss found in the transmitting process is

$$Loss = 20 \log \left|\hat{T}\right| \tag{4.11}$$

However, the mass per unit area of the screen varies depending on its perforation density, and the air flowing through the holes will add another mass to the system. Considering that the performance of perforated screens is similar to the perforated plates' one, used to introduce attenuation in walls in room acoustics, the process to calculate the effective mass of the screen and the correction added to it is going to be through the model proposed by L. Cremer and H. A. Muller.[11]

The data manufacturers provide for Matt Plus Miniperforated is weight for unit area (0.43 kg/m^2), thickness (0.3 mm), perforation density (1.7%) and perforation size (⌀ = 0.5 mm). With these data, the effective weight of the screen

The area of one hole is

$$S_1 = \pi \left(\frac{0.5 \cdot 10^{-3}}{2}\right)^2 = 1.96 \cdot 10^{-7}\ (m^2) \tag{4.12}$$

The whole area covered by the holes is $A_{holes} = 0.017\ m^2$, so the number of holes on it will be:

$$n = \frac{A}{S_1} = 86580\ \left(holes/_{m^2}\right) \tag{4.13}$$

The area which has not been removed from the screen per m^2 is therefore the effective area of the screen

$$A_{perf\ screen} = 1 - A_{holes} = 0.983\ m^2, \tag{4.14}$$

and the effective mass of the screen will be

$$m_{perf} = m \cdot A_{perf\ screen} = 0.43 \cdot 0.98 = 0.4227\ \left(kg/_{m^2}\right) \tag{4.15}$$

The effective mass of the air in the holes is

$$m_1 = \frac{\rho_o \cdot e}{\sigma}, \tag{4.16}$$

where e is thickness in metres and $\sigma = S_1/S_2$; S_2 is the area of the screen associated to each hole. It depends on the distance between holes, both vertical

and horizontal. It can also be calculated by doing the inverse of the number of holes,

$$S_2 = {}^{1}/_{n}\left({}^{m^2}/_{perforation}\right). \tag{4.17}$$

However, the air does not only flow inside of the holes, but also before and after the screen. This movement at both sides of the screen should be added as "hole correction", $2\Delta l$.

$$m_1 = \frac{\rho_o \cdot (e+2\Delta l)}{\sigma} = \frac{\rho_o \cdot (e+1.6r)}{\sigma}. \tag{4.18}$$

Finally, the resultant mass of the perforated screen is a parallel system between m_{perf} and m_1.

$$\frac{1}{m_{res}} = \frac{1}{m_{perf}} + \frac{1}{m_1} \tag{4.19}$$

Also expressed as

$$m_{res} = \frac{m_{perf} \cdot m_1}{m_{perf} + m_1} \tag{4.20}$$

Therefore,

$$m_1 = \frac{1.21 \cdot (0.3 \cdot 10^{-3} + 1.6 \cdot 0.25 \cdot 10^{-3})}{1.96 \cdot 10^{-7} \Big/ \frac{1}{86580}} = 0.0498 \left({}^{kg}/_{m^2}\right)$$

And the resulting mass applied to the mechanical impedance is

$$m_{res} = \frac{0.4227 \cdot 0.0498}{0.4227 + 0.0498} = 0.0446 \left({}^{kg}/_{m^2}\right)$$

4.1. Results for perforated screen

The results obtained for frequencies around 5 kHz are considerably good, and for frequencies below it adds a bit of gain, whereas for frequencies over 5 kHz the model adds more attenuation than it should.

In Fig. 4-1 and Fig. 4-2 can be seen the modelled attenuation in comparison with the real screen at different distances from the loudspeaker.

Fig. 4-3 and Fig. 4-4 show the modelled attenuation and an average of the real attenuation. The discontinuous lines show the maximum and minimum attenuation measured.

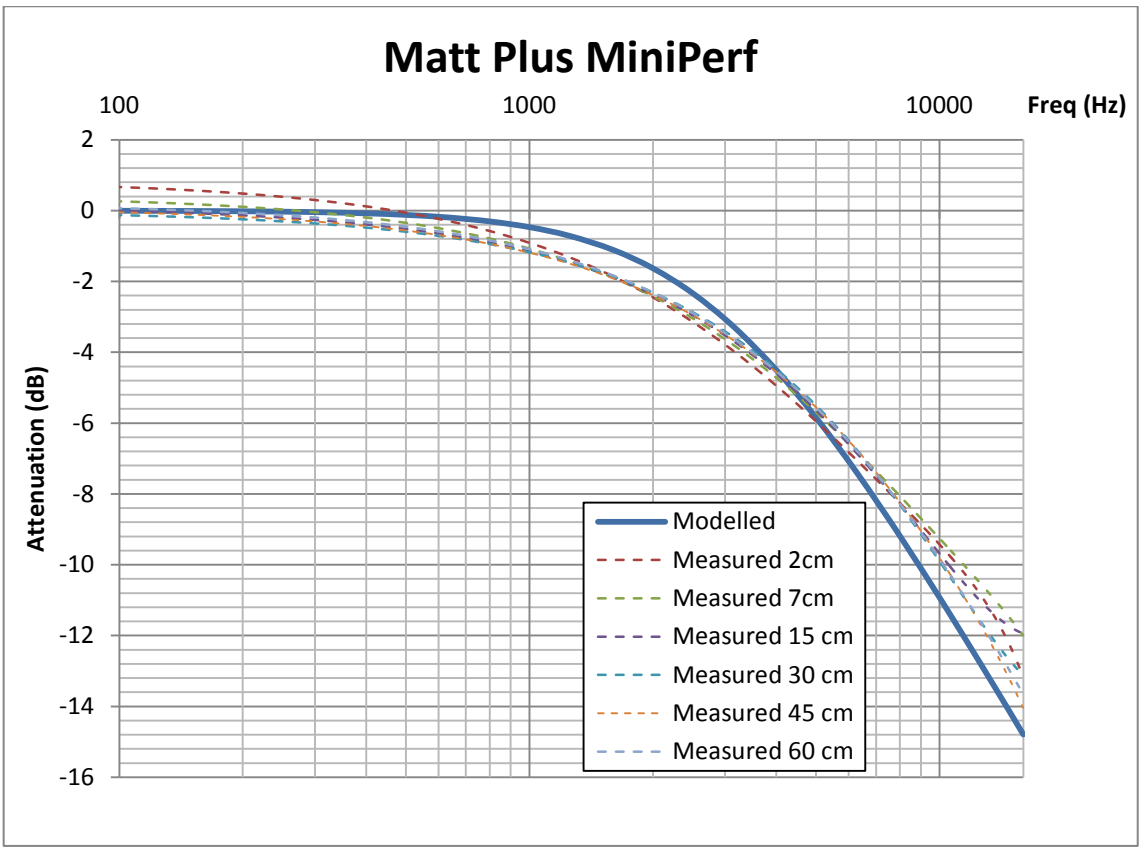

Fig. 4-1: Comparison between the modelled and the measured attenuation at different distances from the screen. (More visible results at low frequencies)

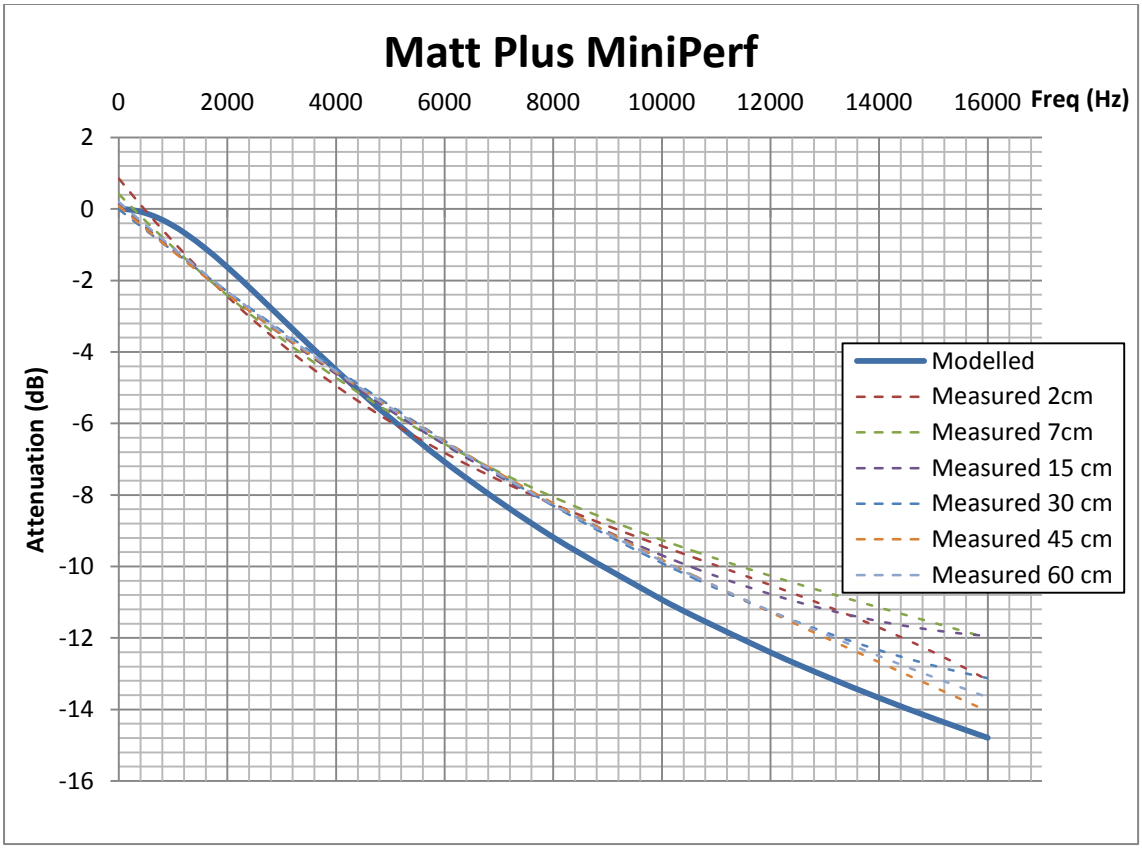

Fig. 4-2: Comparison between the modelled and the measured attenuation at different distances from the screen. (More visible results at high frequencies)

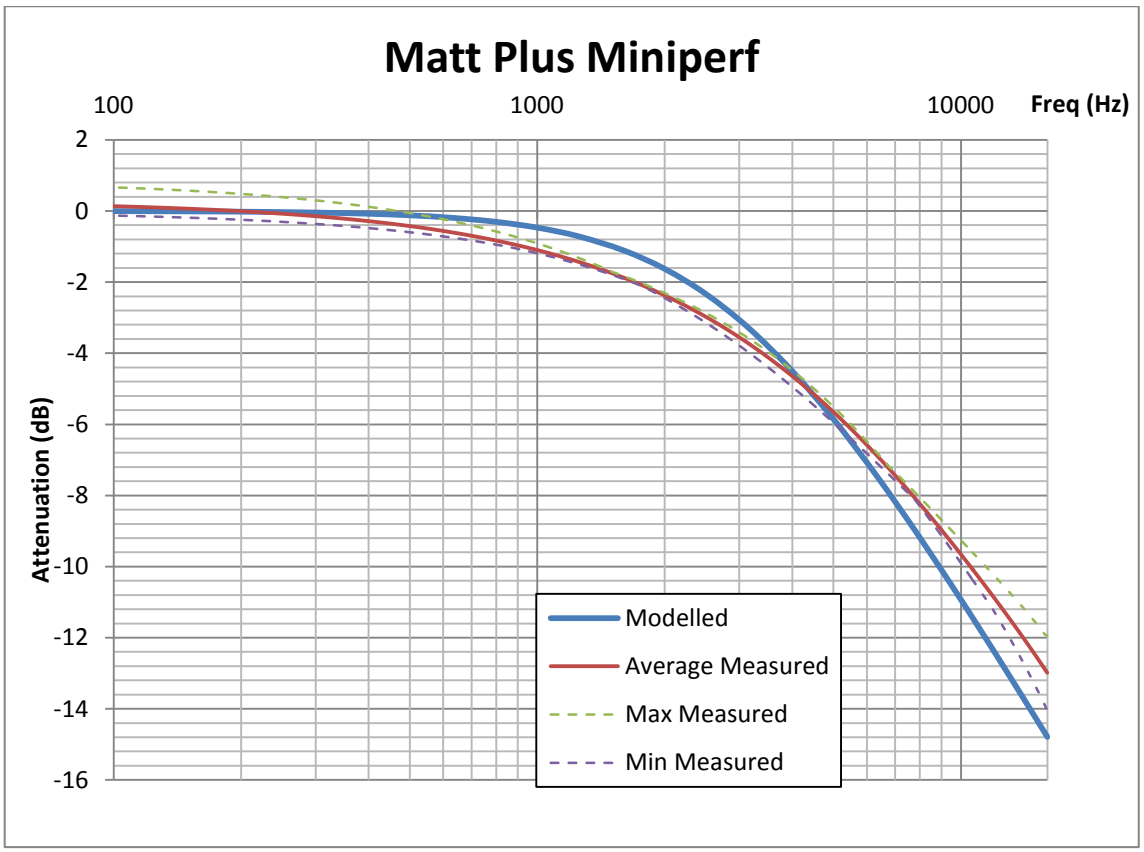

Fig. 4-3: Comparison between the modelled and the average measured attenuation.
(More visible results at low frequencies)

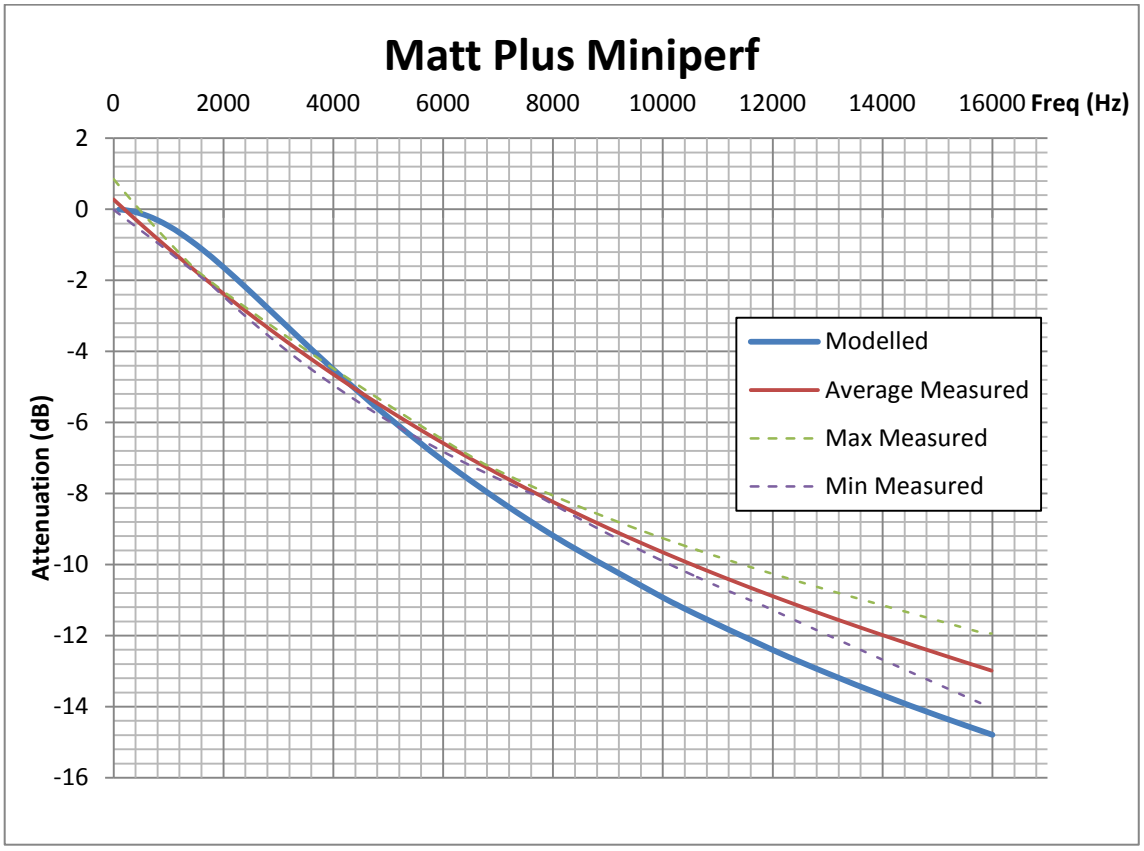

Fig. 4-4: Comparison between the modelled and the average measured attenuation.
(More visible results at high frequencies)

4.2. Ways to reduce the attenuation in perforated screens

In the purposed model, the perforation size and density can be varied. This would be a good way to predict which parameters of a screen are necessary to obtain a certain loss.

If the size diameter is reduced, the loss will be smaller than it is now; however, the most efficient way to reduce this attenuation would be i ncreasing the perforation density, although this could lead to a deterioration in the quality of the image projected on the screen.

In the following graph, it will be s hown a graph provided by Harkness Screens which looked at together with the characteristics of their different screens (Table 4) is clear the above stated.

Table 4: Characteristics of different perforated screens by Harkness Screens

Screen model	Perf size (mm)	Perf Density (%)
Matt Plus Standard	1,2	4,5
Matt Plus MiniPerforated	0,5	1,7
Matt Plus MiniPerforated Super	0,5	5,1

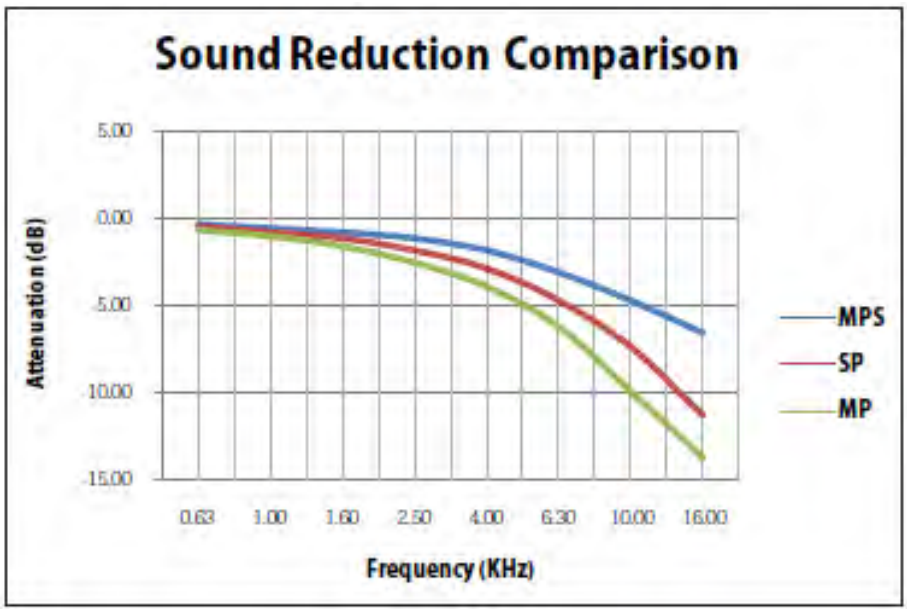

Fig. 4-5: Attenuation variation depending on the perforation size and density.

5. Conclusions and further work

The aim of this report was finding out which is the acoustical variation cinema screens add to the original sound when they are placed in front of a loudspeaker.

It must be said that these variations change depending on the type of screen as woven and perforated screens behave differently.

Each screen is made of a different material with different characteristics according to what the cinema or cinematic room needs. When deciding the best screen to place in a cinema it should be borne in mind two main aspects: which **gain** is necessary for the cinema dimensions and screen projector used, as some materials reflect the light in a more uniform way in all directions. If a screen has a 0 gain it means that the position chosen to see the projection will not be important as all viewers will watch the image with the same brightness. Materials with higher gain will reflect the light towards the centre of the vision area, and viewers sitting near to the sides of the room will perceive a darker image. In addition to the gain, the **acoustical transparency** of the screen material is a characteristic equally important as it is the one in charge of letting the sound coming from the loudspeakers (ideally placed behind the screen) go directly through the screen. If the screen is not acoustical transparent the screen loudspeaker can be placed on top or underneath the screen to avoid the distortion caused by the screen.

Once the screen has been chosen bearing in mind these parameters, the distance to the loudspeaker is one of the biggest issues to decide. According to all the measurements taken for this project, it has come to the conclusion that the best distance to place the screen would be 30 cm for all screens, as for the woven ones it is the distance at which the tendency of the Pressure Transmitting Factor (PTF) remains more constant and for perforated screens at high frequencies they appear to be very opaque, however, with an audio processor to

enhance these range of frequencies this problem could be solved. Furthermore, at this distance, the frequency response for all the screens is the one which looks better with a smaller amplitude difference between the peaks and dips which appear at the frequencies where the comb filtering takes place. It should be highlighted that for screens angled 10 degrees with respect to the loudspeaker, the comb filtering effect is less prominent, which is a fact of great interest for left and right screen loudspeakers.

According to the cepstrum analysis, the distance which might be better to place the screen is 15 or 30 cm, as there are few late arrivals captured by the microphone at 15 cm than at 30 cm, and their amplitude is also smaller. So, it should be chosen whether to receive less late arrivals or experiencing a not so acoustically transparent screen as it was said before. It is to say that at a distance of 30 cm, there last late arrival will get to the microphone 7 ms later than the direct signal, meaning that it should not interfere either in the clarity of speech or music.

According to a survey held by Brawn Consulting for Stewart Filmscreen[12] in 2006, the distance at which a perforated screen should be placed from the loudspeaker should never been less than 30 cm. And in every test carried out by them in which this recommended distance was not respected, comb filtering occurred, whereas installed to this specification, minimal attenuation took place. Throughout this report has been proved that comb filtering appears at all distances, even though if the distance is larger than 30 cm; plus an increase in this distance will lead to more delayed late arrivals as the reflected wave has to cover a larger path.

This way, screen loudspeakers could be placed as Fig. 5-1 for wide cinemas or cinematic rooms, or like Fig. 5-2 for narrower ones.

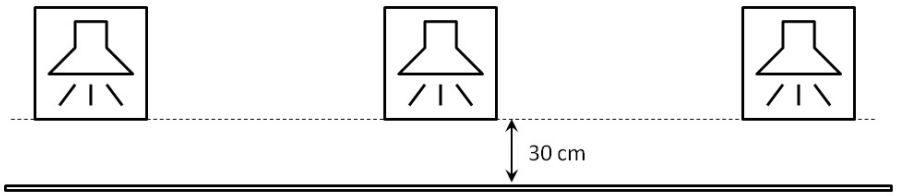

Fig. 5-1: Screen loudspeakers placed at a distance of 30 cm from the screen sheet.

Fig. 5-2: Left and right screen loudspeakers placed forming a 10 degrees angle with the screen sheet

In future studies the distances to measure these aspects could be limited between 20 cm and 50 cm; this way, it would be easier to find a much more precise distance depending on the type of screen selected. Another interesting aspect that could be further studied is how loudspeakers change their directivity pattern depending on the distance screens are placed in front of them. There is no information covering this aspect in loudspeakers datasheets and it might be of considerable help for cinema installations.

References

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[12] ALAN C. BRAWN CTS, ISF, AIA (2006), *White Paper: Perforated Screens.* Available from: http://www.stewartfilmscreen.com/commercial/resources/wp_perforated_screens/wp_perforated_screens_commercial.html

Appendices

As an electronic copy has been submitted together with this report, in order to preserve the environment, all the figures found in the appendices will be printed in black and white.

Appendix A:

Frequency Responses

A. 1. Enlightor 4K

Frequency response for screen Enlightor 4K at a distance of 2cm

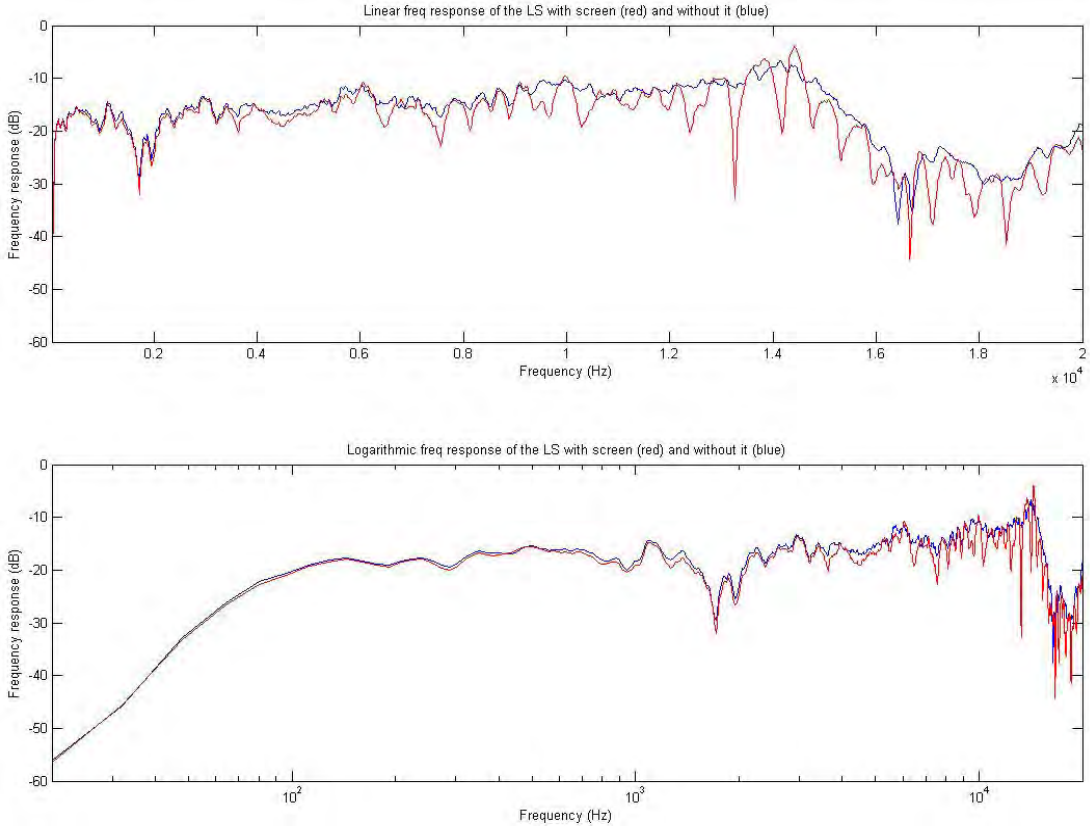

Fig. A. 1: Freq. response for screen Enlightor 4K at a distance of 2cm. 0 degrees

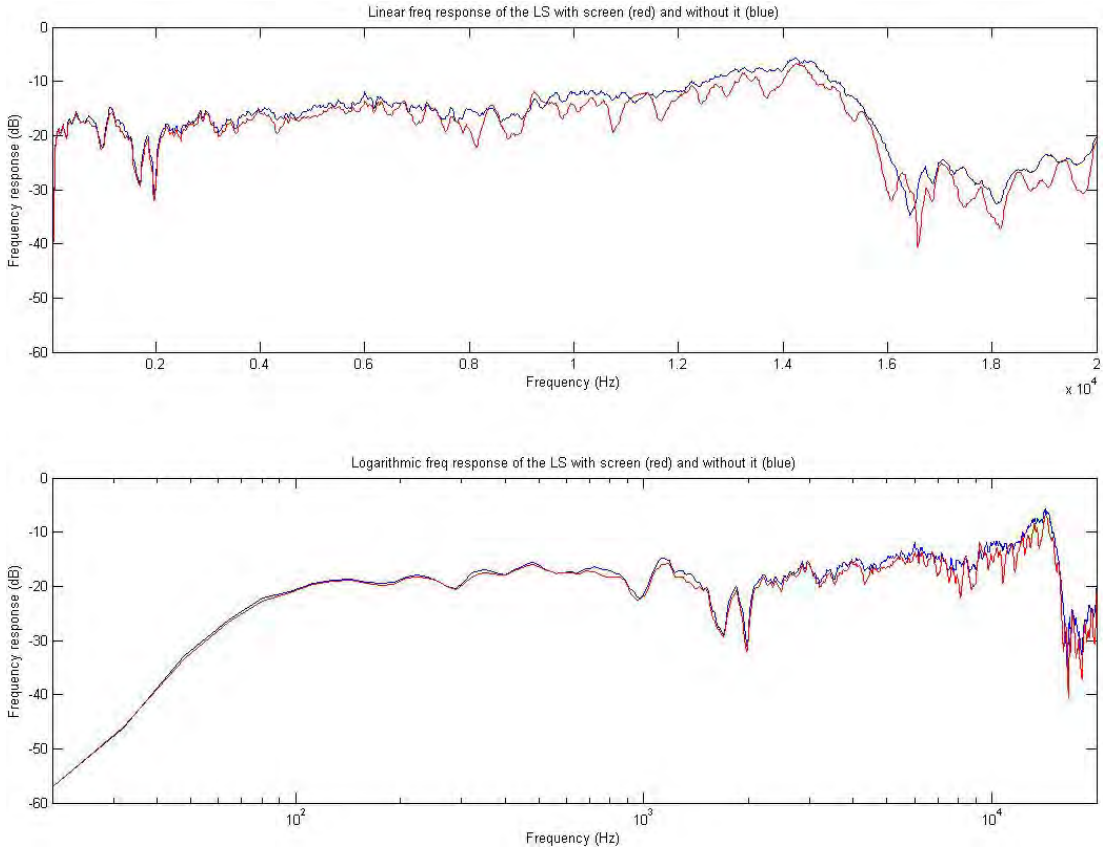

Fig. A. 2: Freq. response for screen Enlightor 4K at a distance of 2cm. 15 degrees

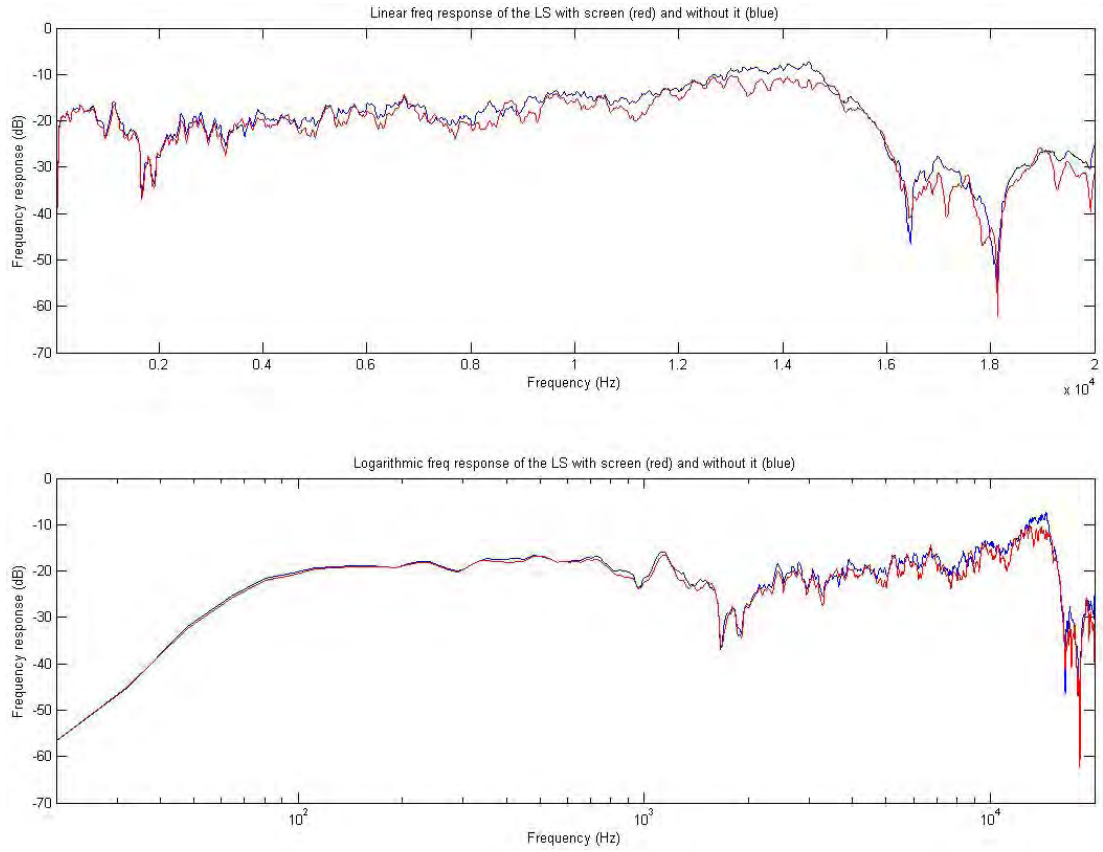

Fig. A. 3: Freq. response for screen Enlightor 4K at a distance of 2cm. 30 degrees

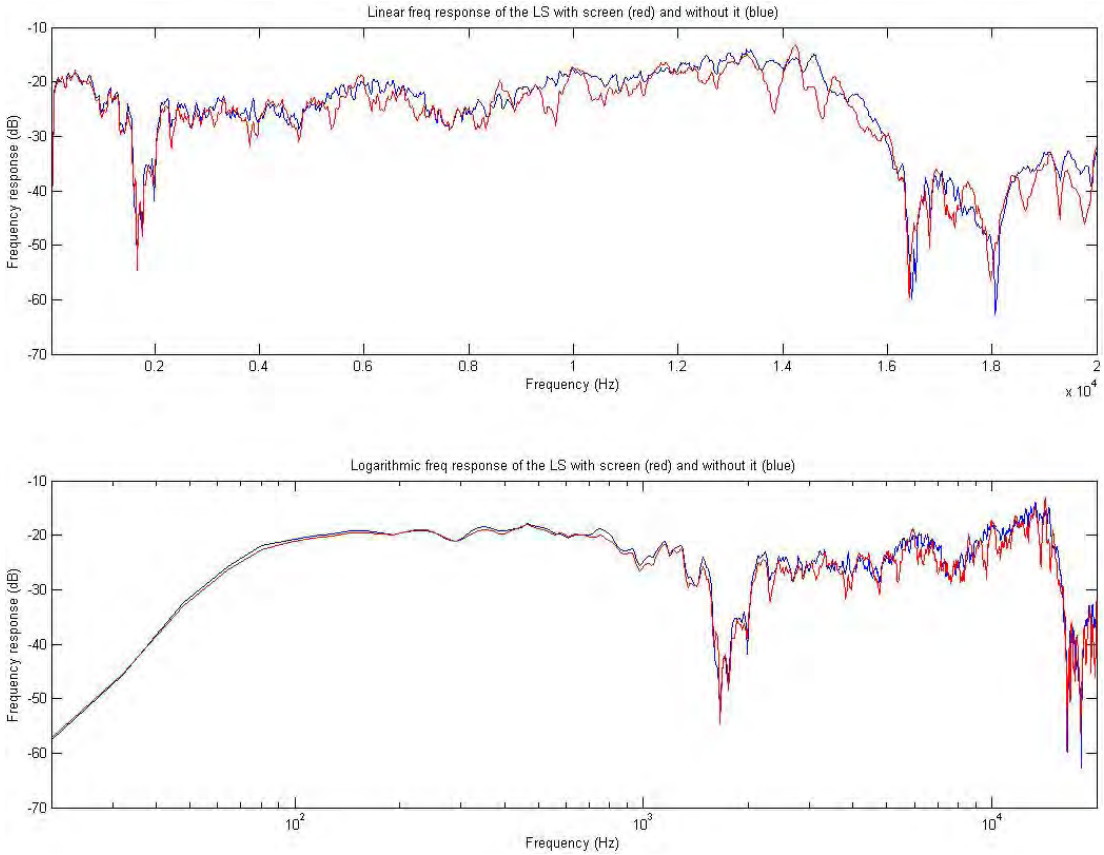

Fig. A. 4: Freq. response for screen Enlightor 4K at a distance of 2cm. 45 degrees

Frequency response for screen Enlightor 4K at a distance of 7cm

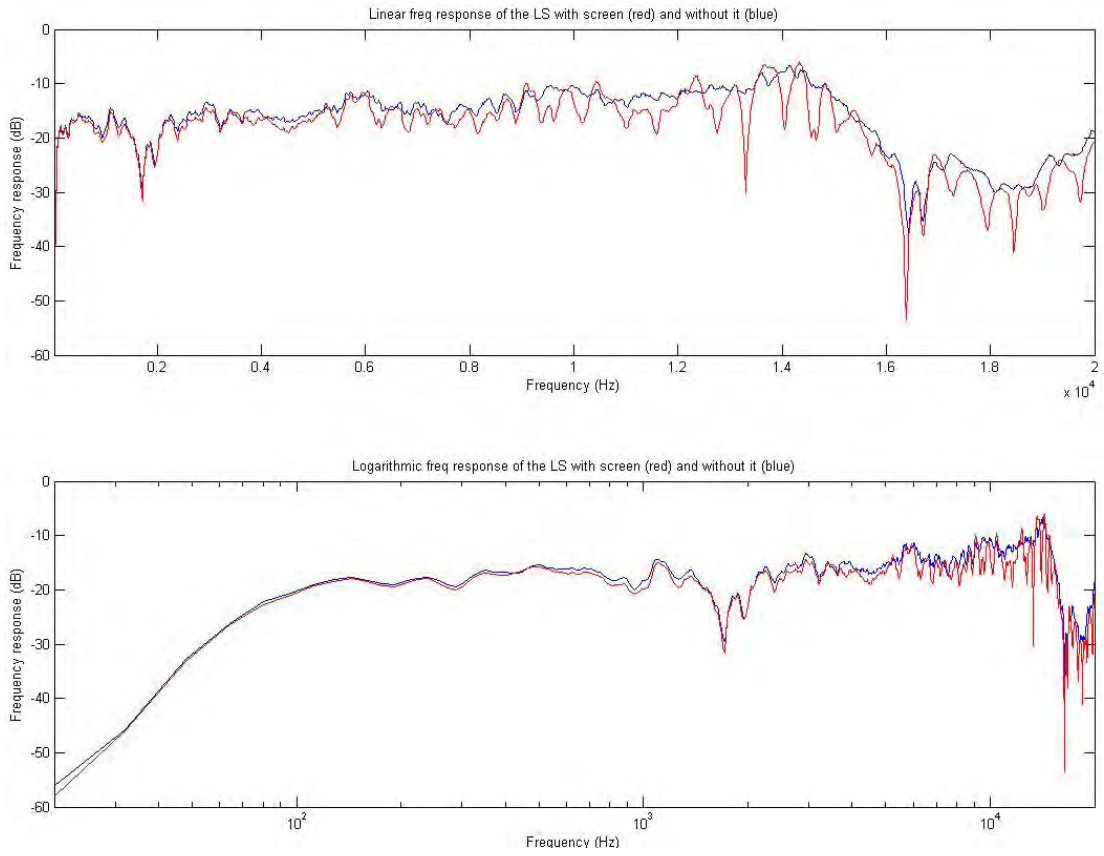

Fig. A. 5: Freq. response for screen Enlightor 4K at a distance of 7cm. 0 degrees

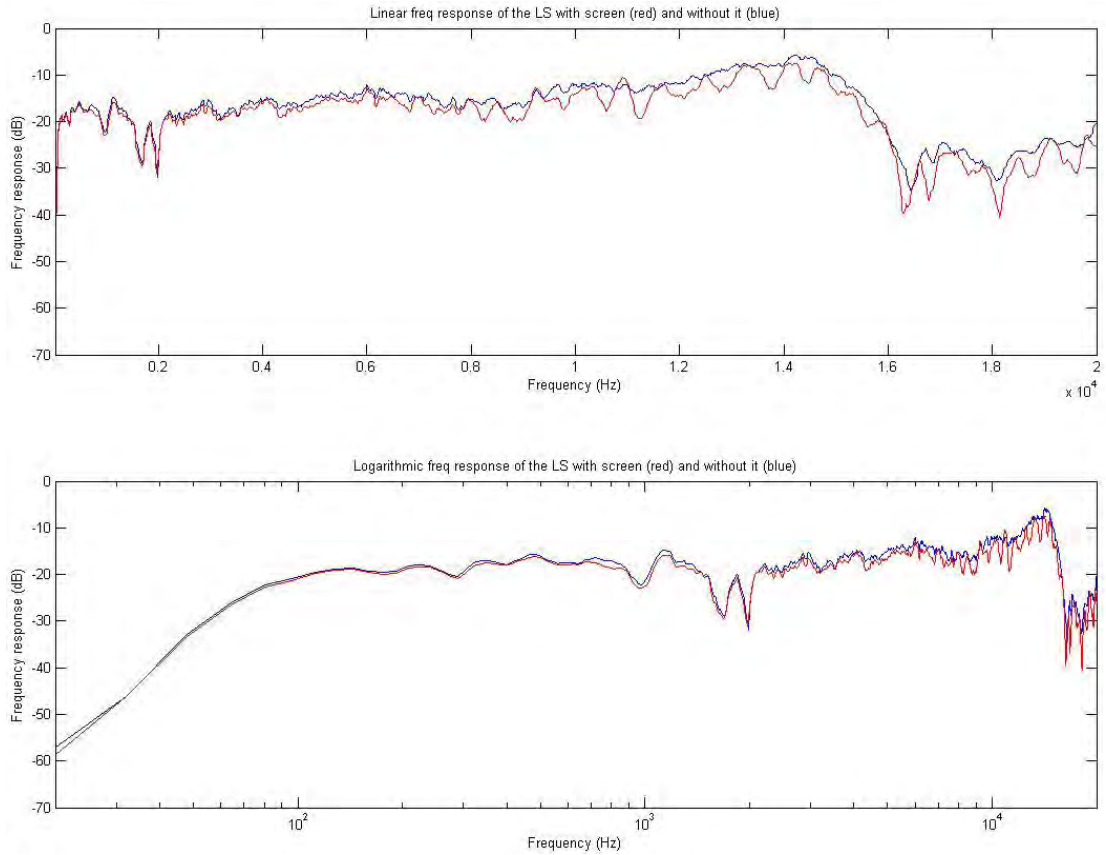

Fig. A. 6: Freq. response for screen Enlightor 4K at a distance of 7cm. 15 degrees

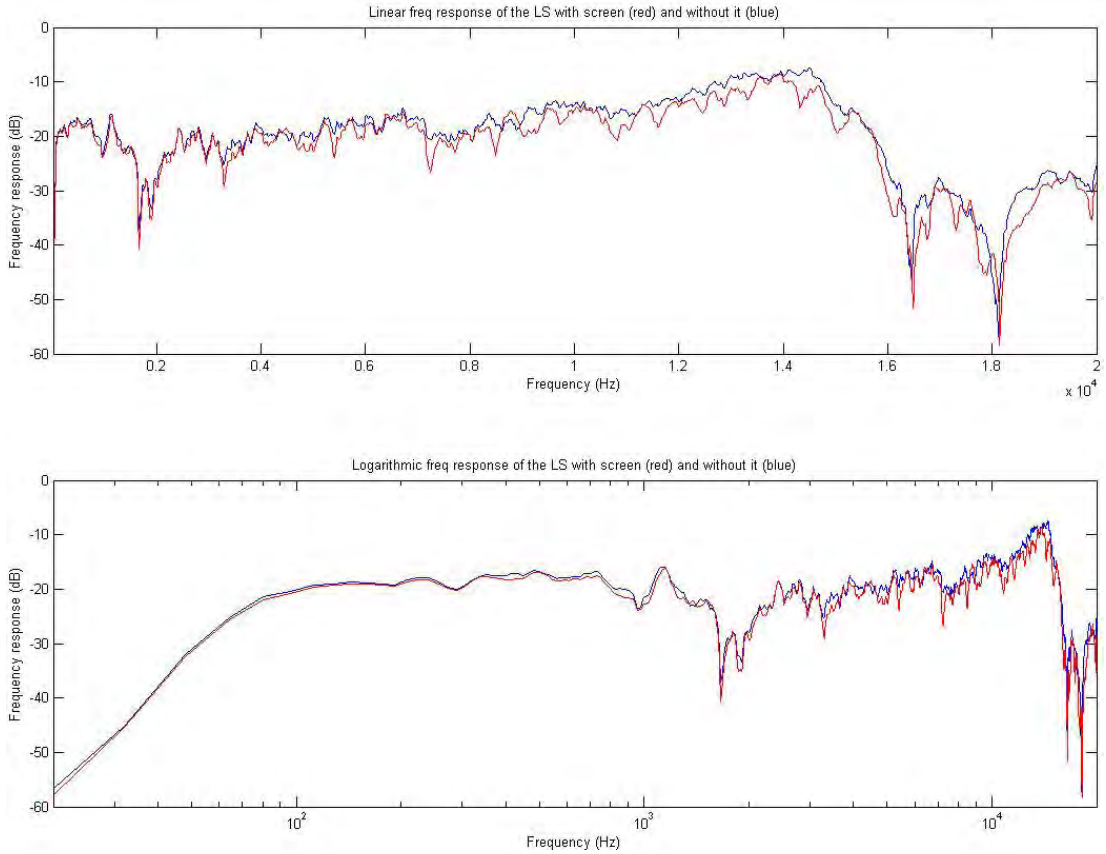

Fig. A. 7: Freq. response for screen Enlightor 4K at a distance of 7cm. 30 degrees

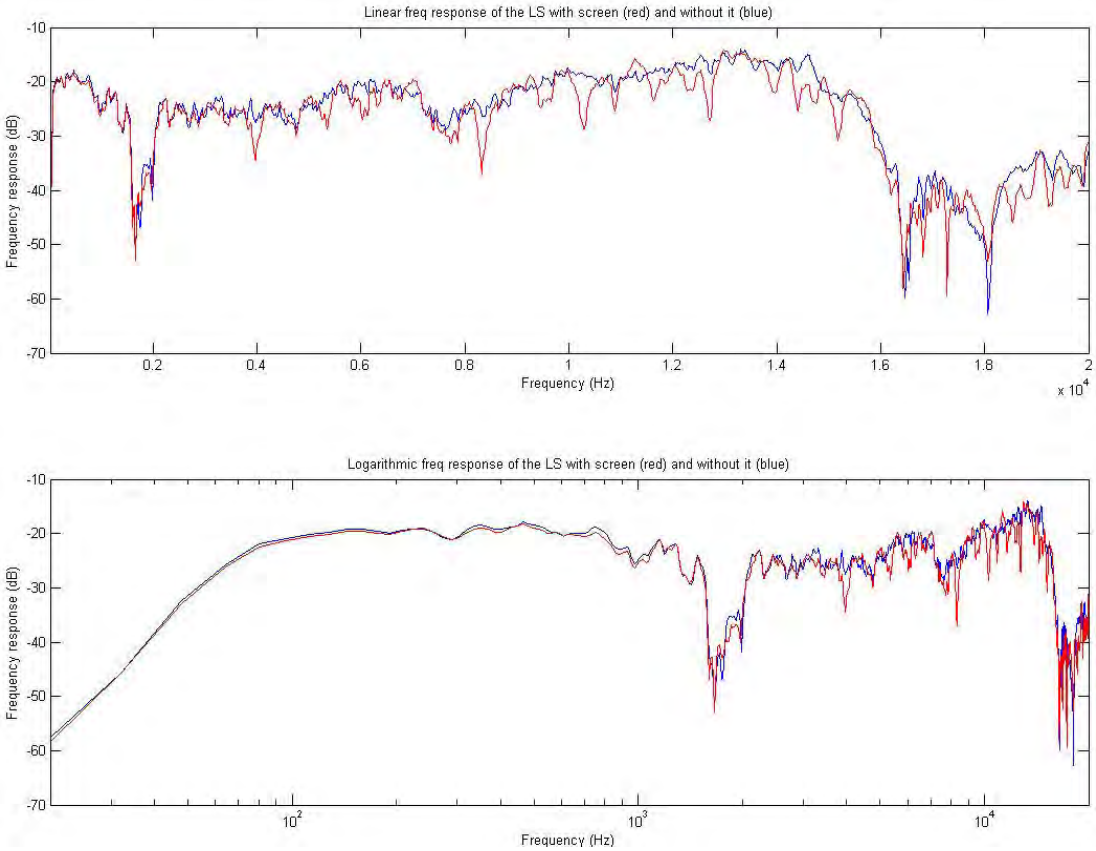

Fig. A. 8: Freq. response for screen Enlightor 4K at a distance of 7cm. 45 degrees

Frequency response for screen Enlightor 4K at a distance of 15cm

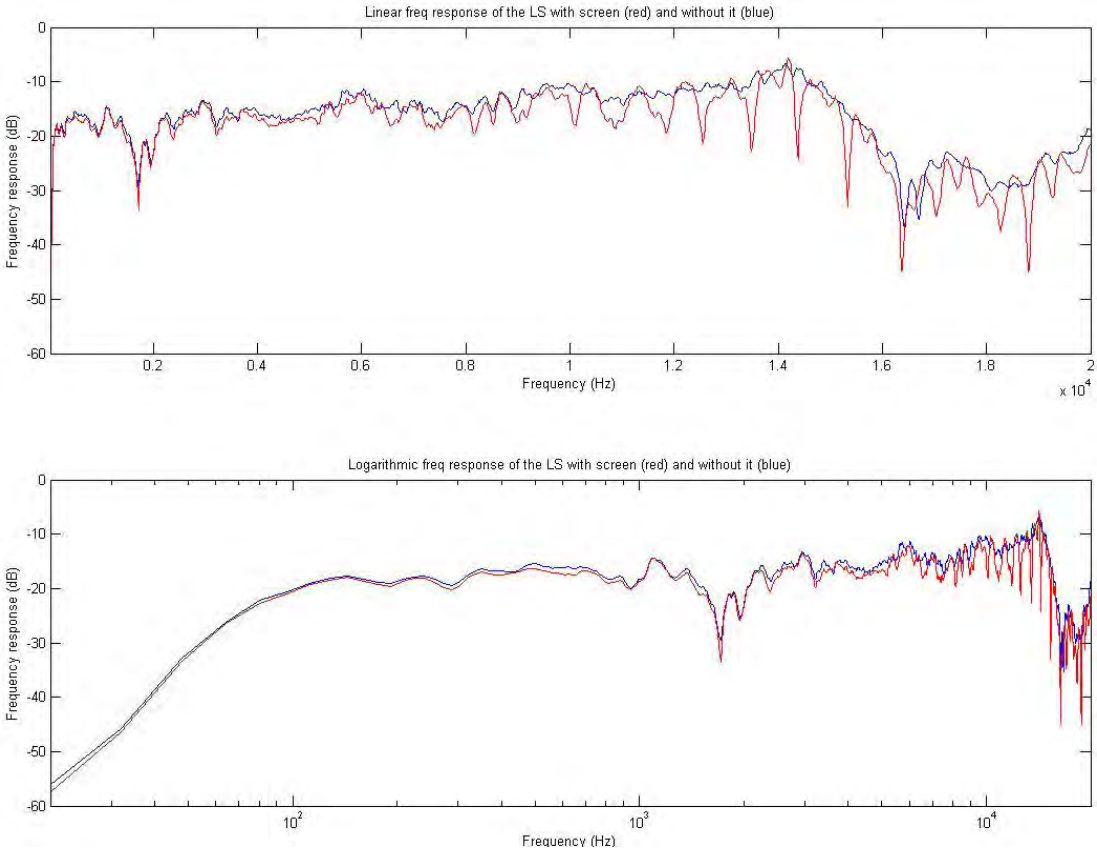

Fig. A. 9: Freq. response for screen Enlightor 4K at a distance of 15cm. 0 degrees

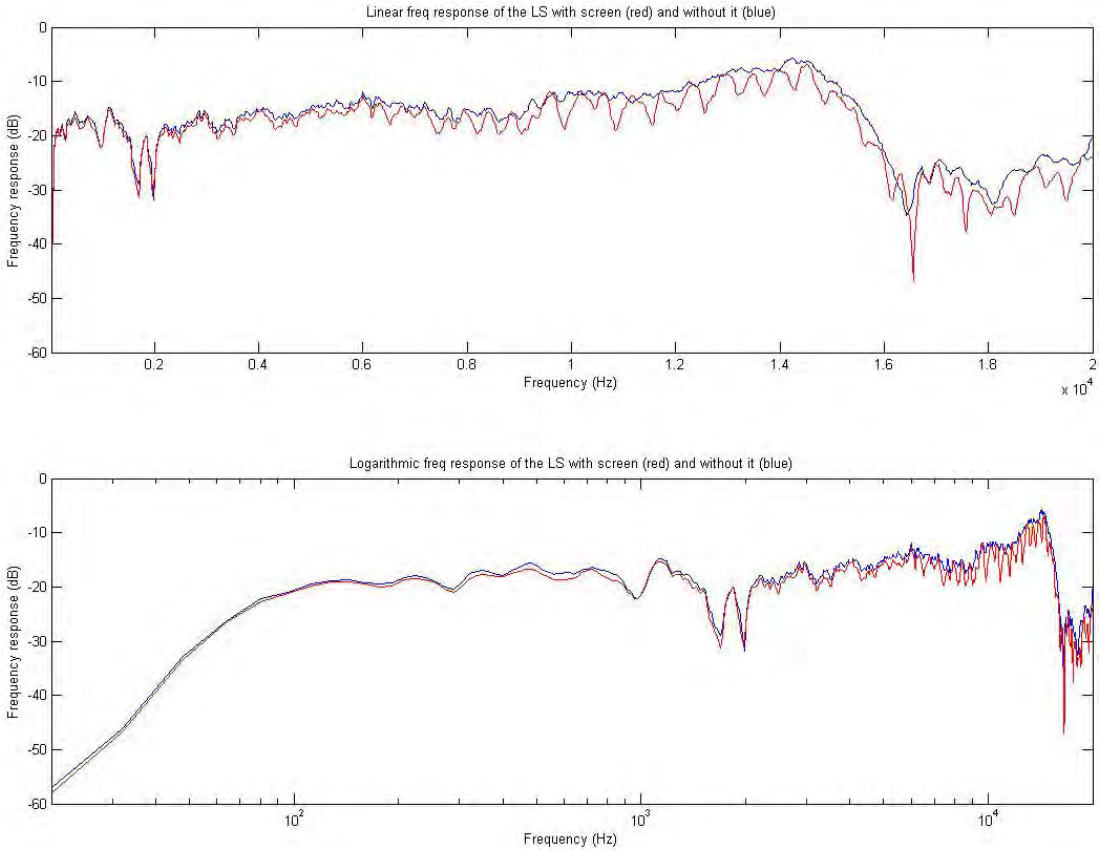

Fig. A. 10: Freq. response for screen Enlightor 4K at a distance of 15cm. 15 degrees

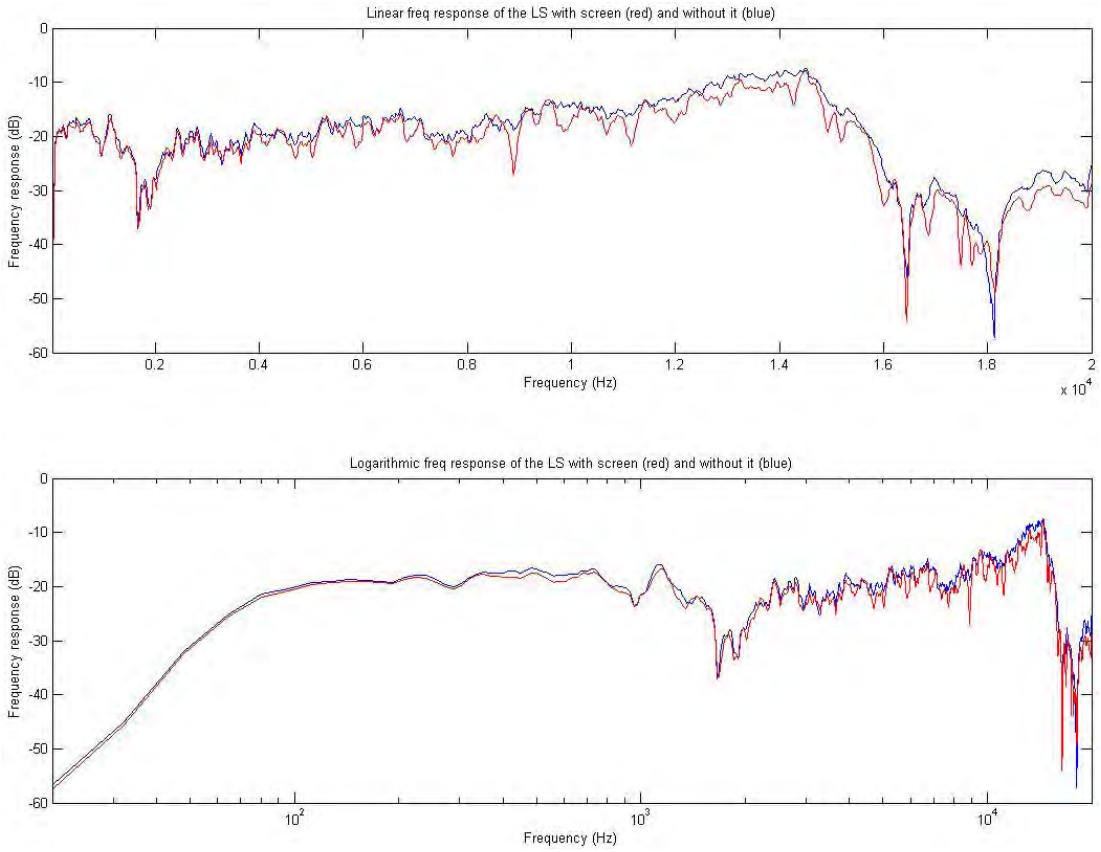

Fig. A. 11: Freq. response for screen Enlightor 4K at a distance of 15cm. 30 degrees

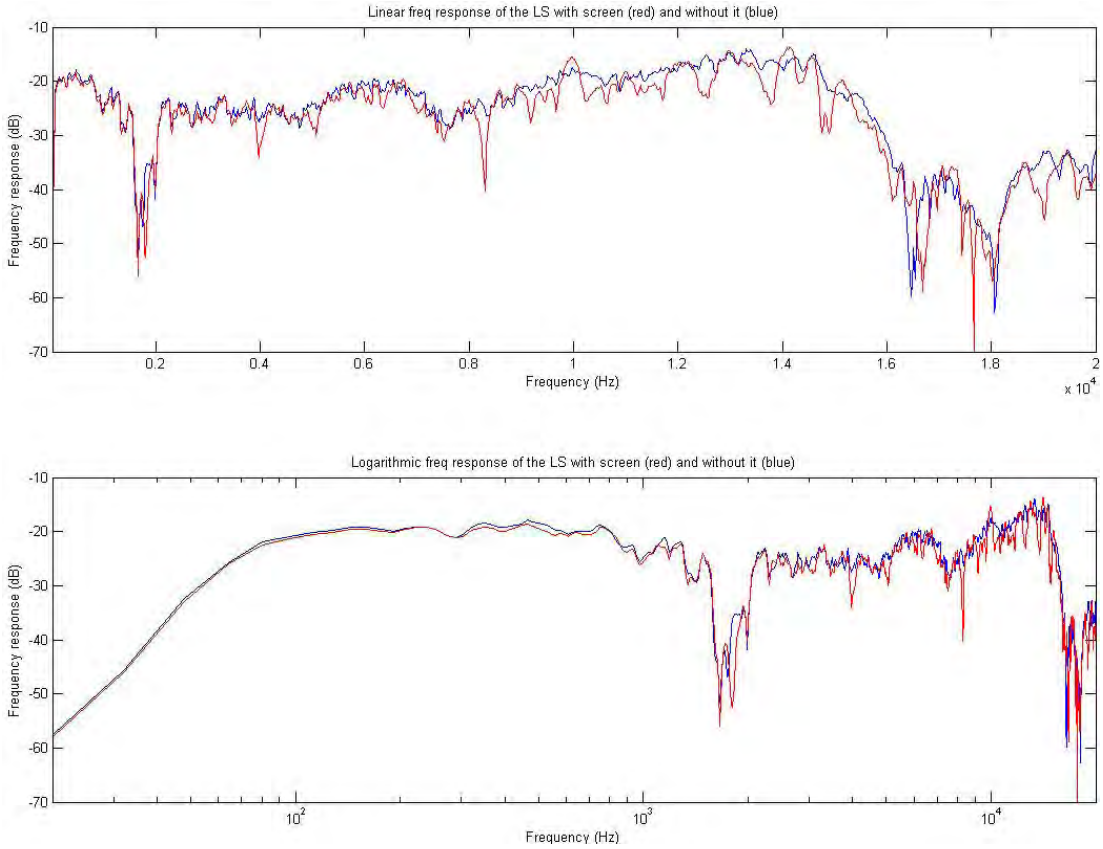

Fig. A. 12: Freq. response for screen Enlightor 4K at a distance of 15cm. 45 degrees

Frequency response for screen Enlightor 4K at a distance of 30cm

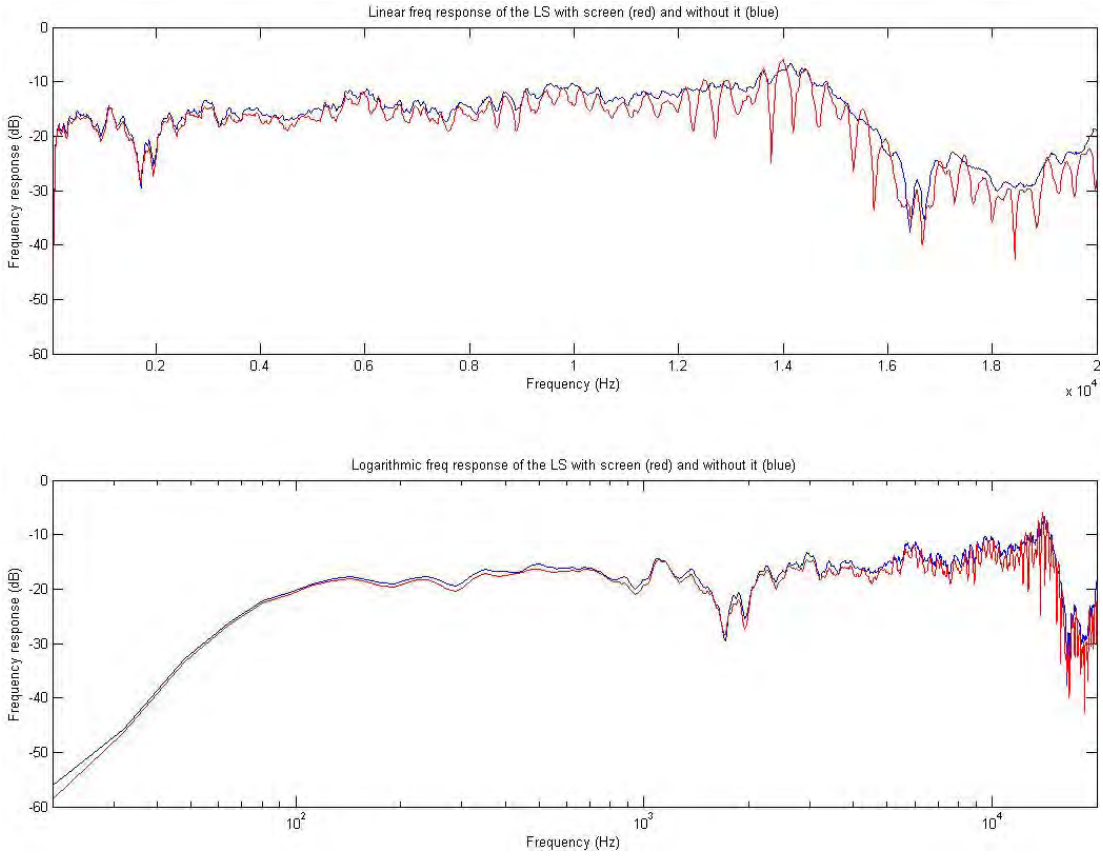

Fig. A. 13: Freq. response for screen Enlightor 4K at a distance of 30cm. 0 degrees

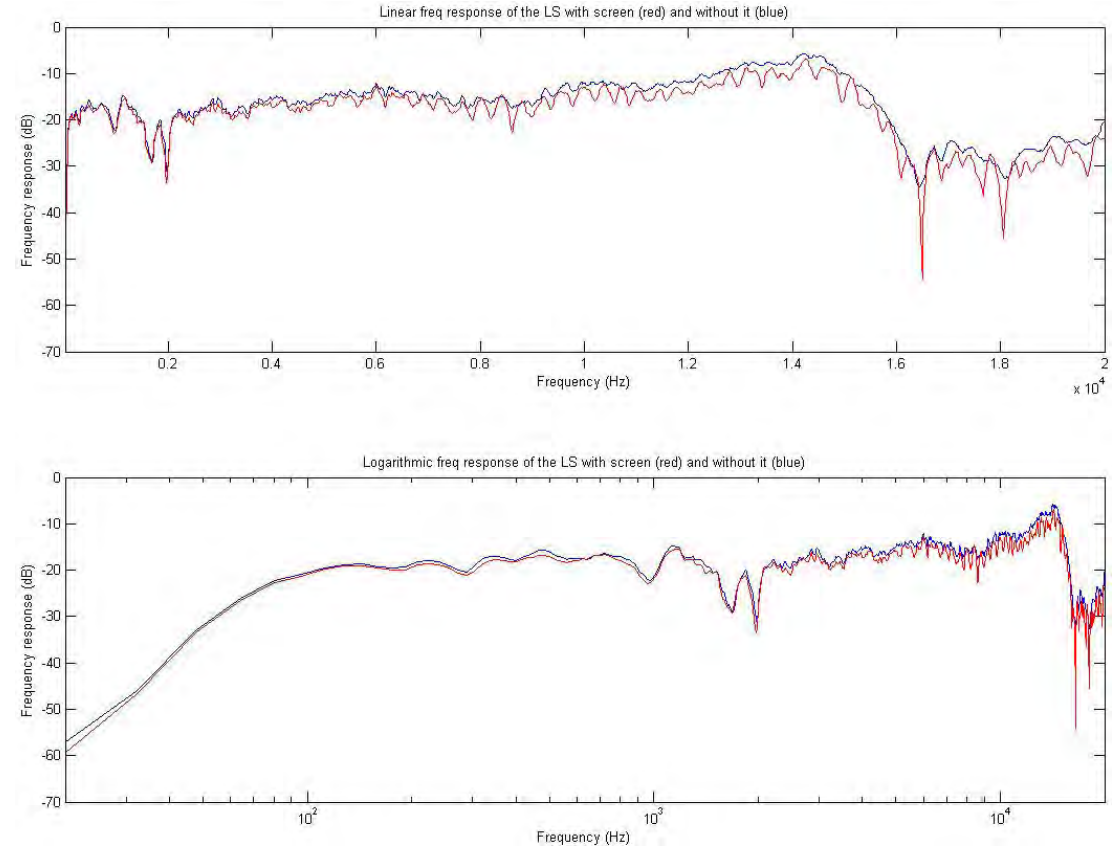

Fig. A. 14: Freq. response for screen Enlightor 4K at a distance of 30cm. 15 degrees

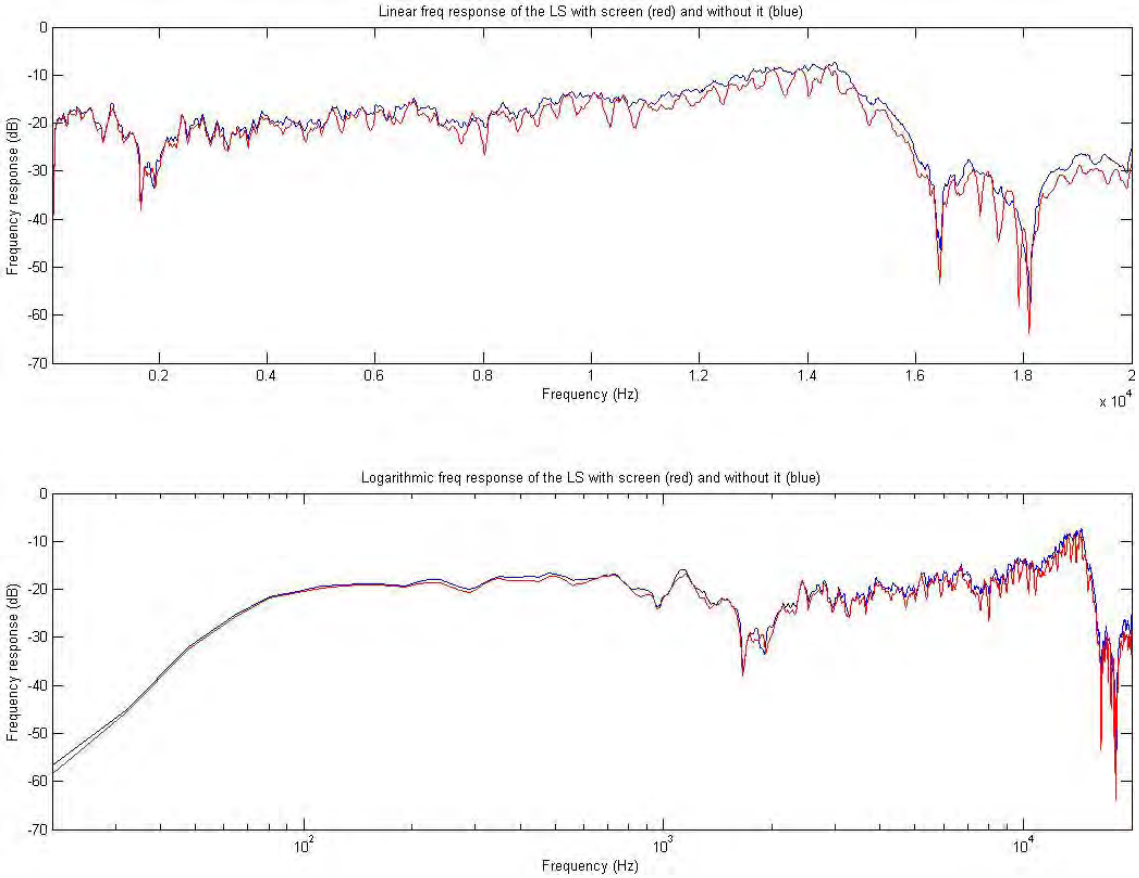

Fig. A. 15: Freq. response for screen Enlightor 4K at a distance of 30cm. 30 degrees

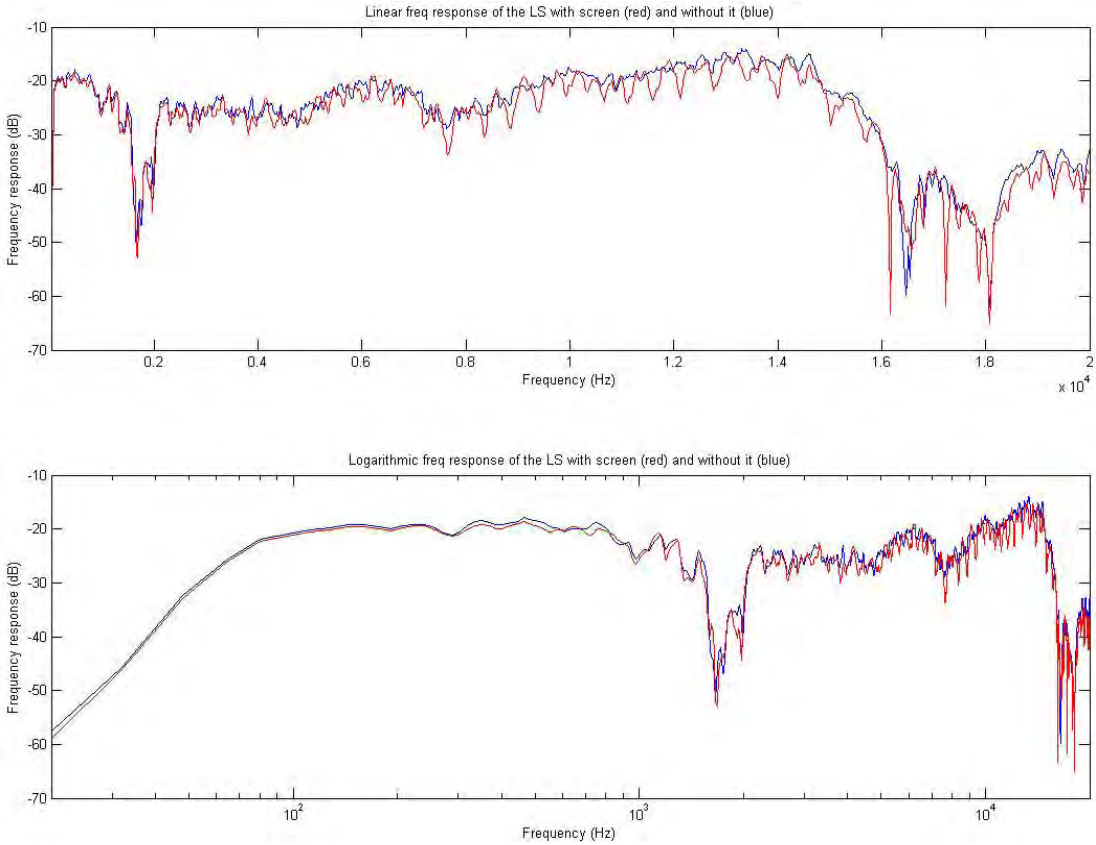

Fig. A. 16: Freq. response for screen Enlightor 4K at a distance of 30cm. 45 degrees

Frequency response for screen Enlightor 4K at a distance of 45cm

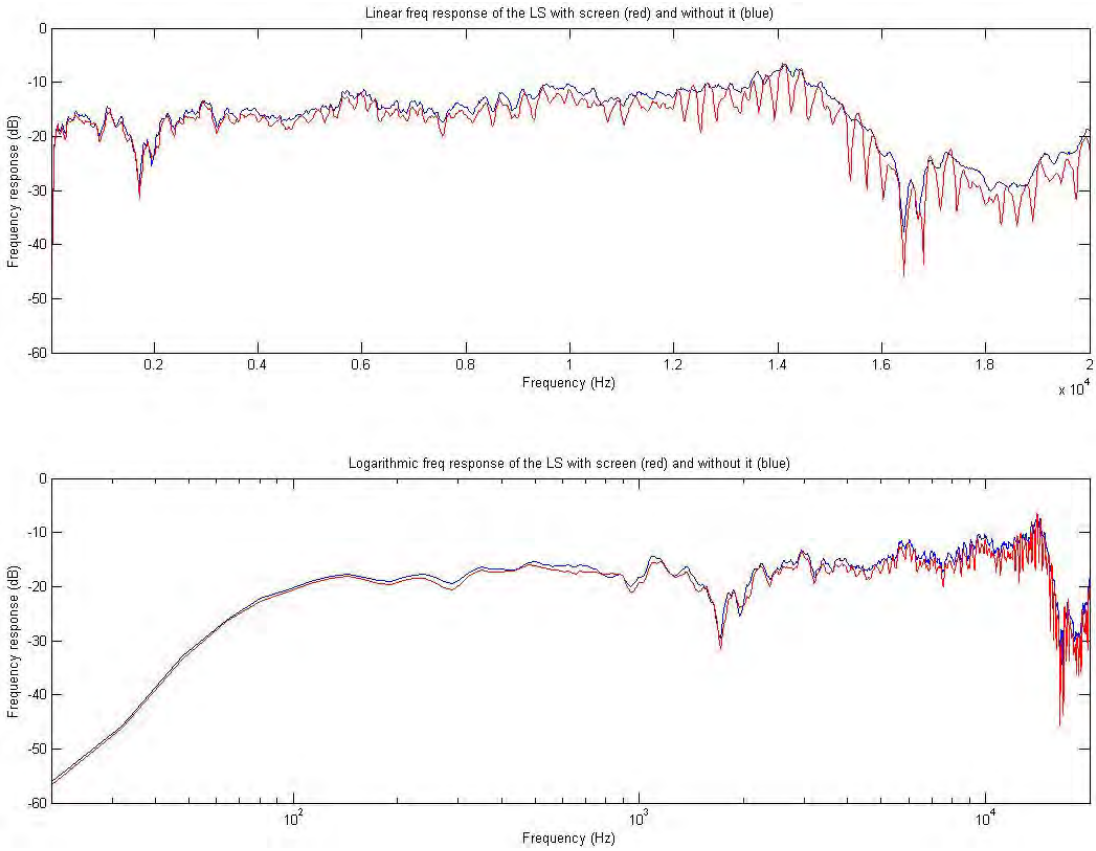

Fig. A. 17: Freq. response for screen Enlightor 4K at a distance of 45cm. 0 degrees

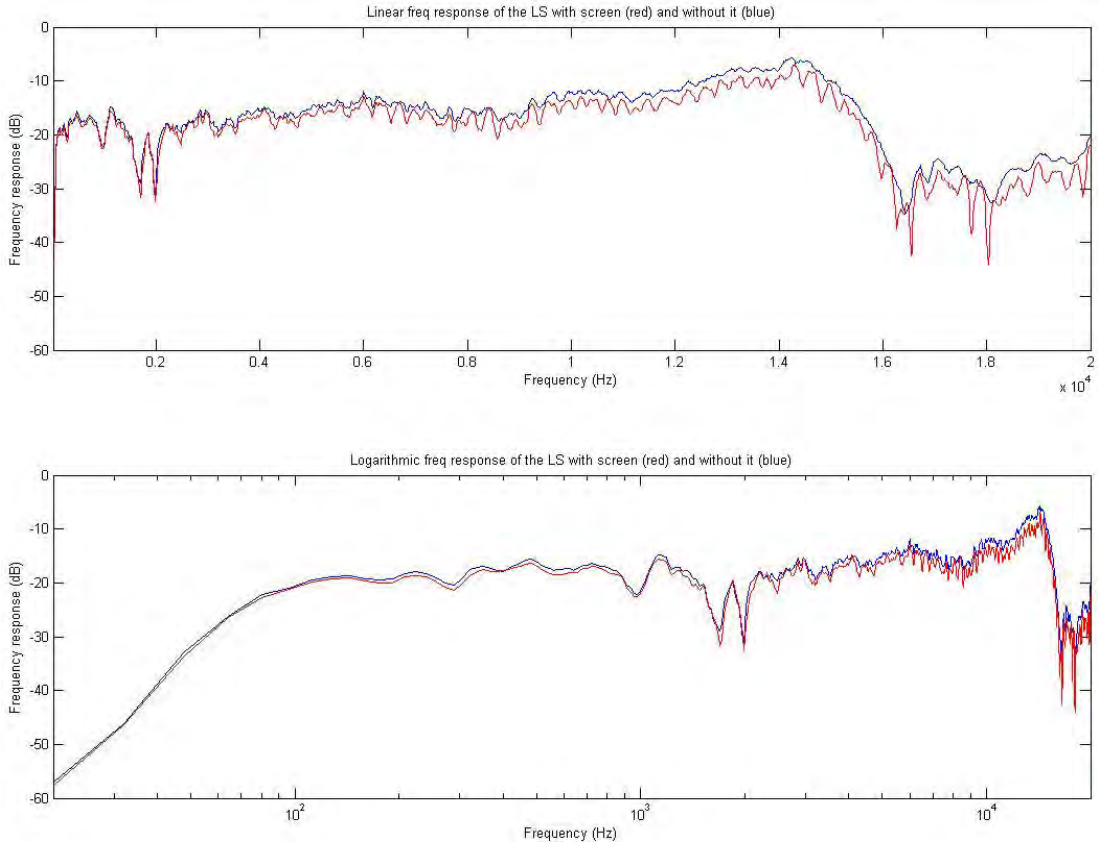

Fig. A. 18: Freq. response for screen Enlightor 4K at a distance of 45cm. 15 degrees

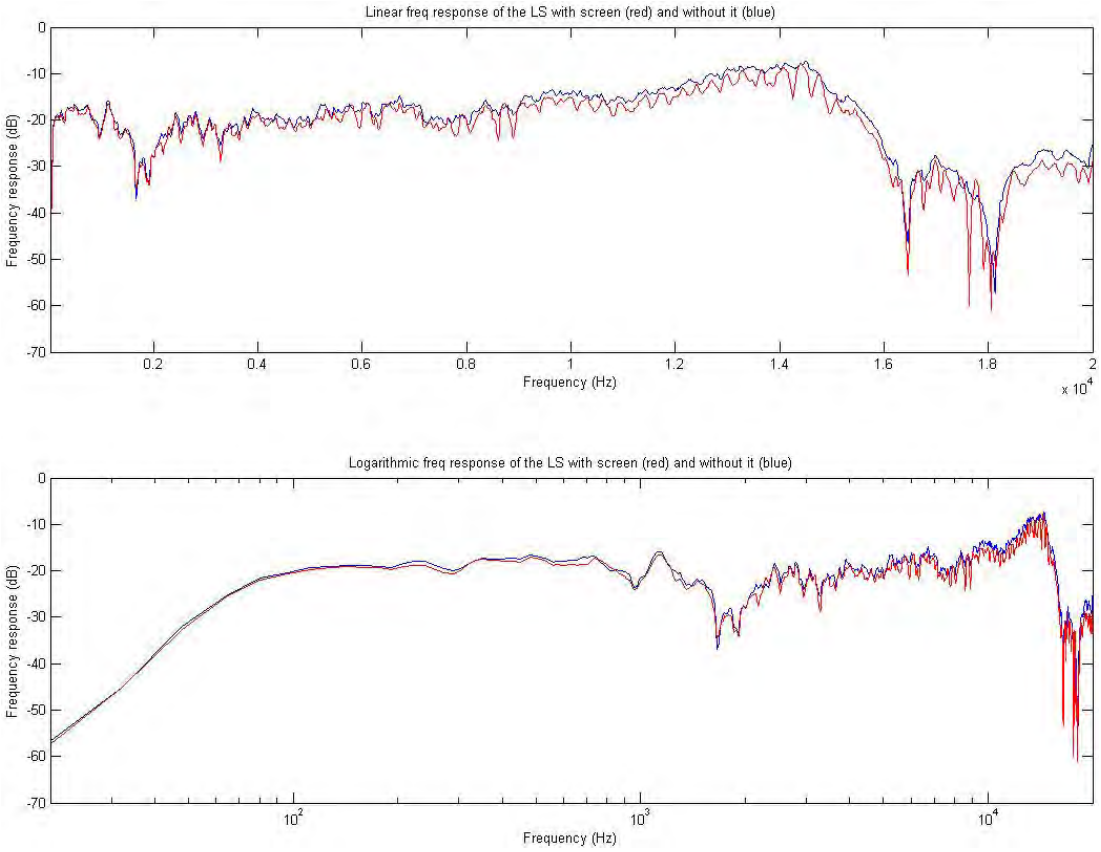

Fig. A. 19: Freq. response for screen Enlightor 4K at a distance of 45cm. 30 degrees

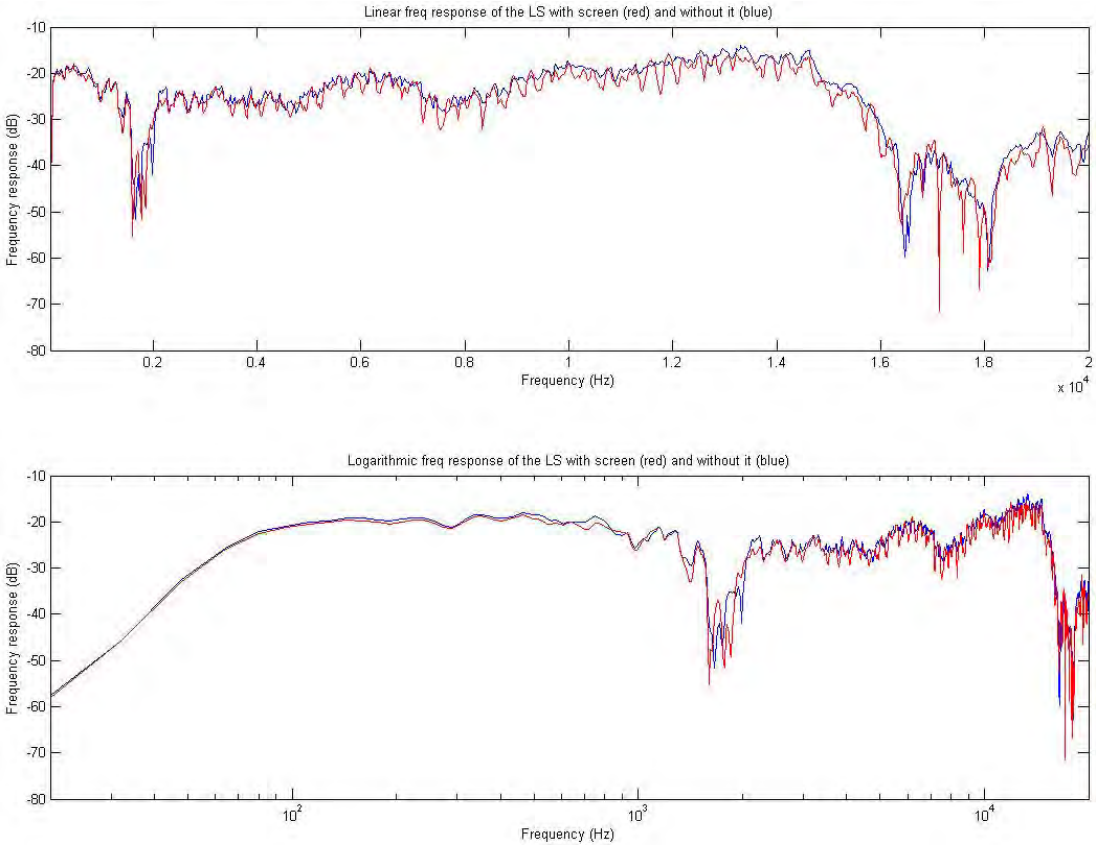

Fig. A. 20: Freq. response for screen Enlightor 4K at a distance of 45cm. 45 degrees

Frequency response for screen Enlightor 4K at a distance of 60cm

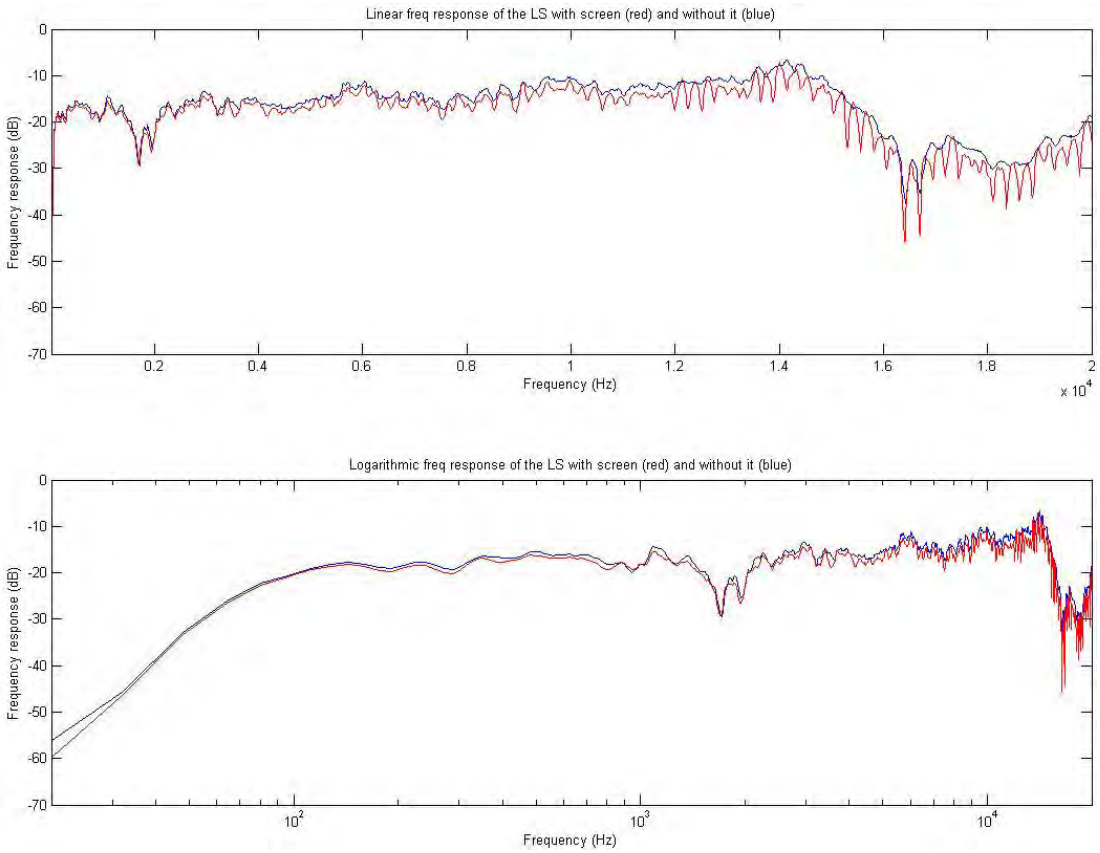

Fig. A. 21: Freq. response for screen Enlightor 4K at a distance of 60cm. 0 degrees

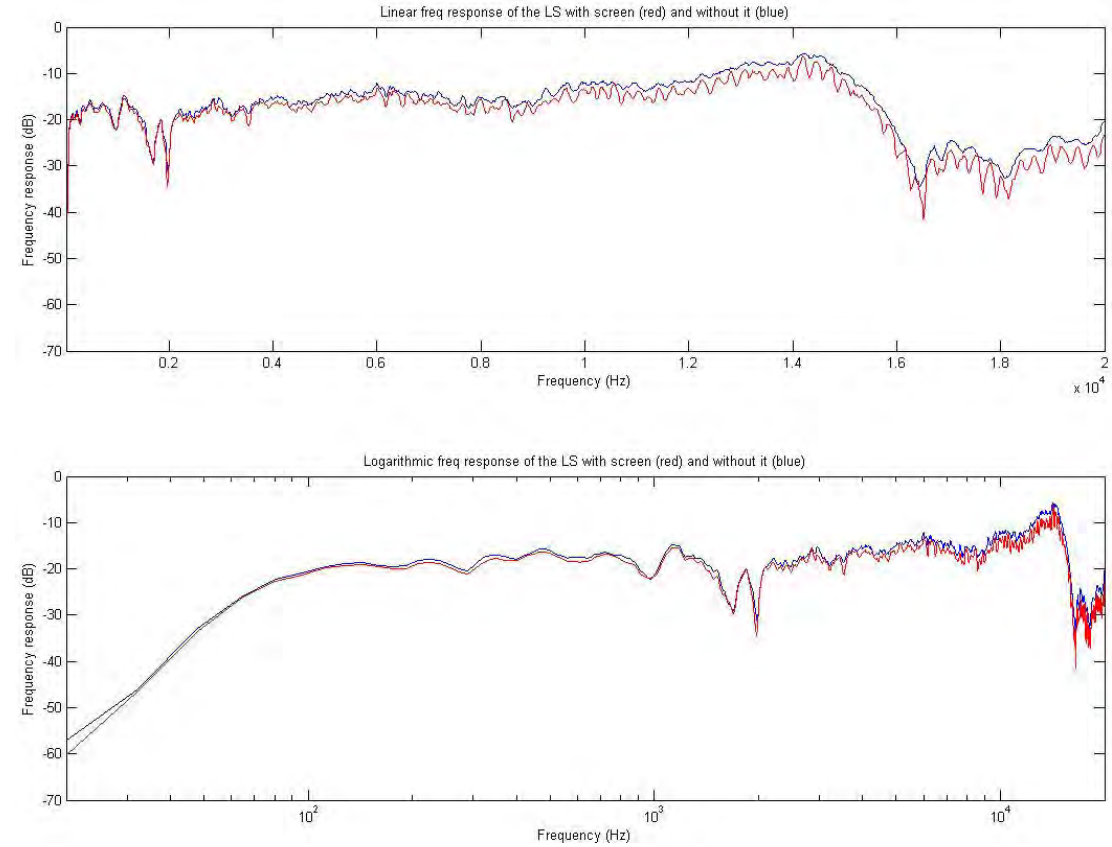

Fig. A. 22: Freq. response for screen Enlightor 4K at a distance of 60cm. 15 degrees

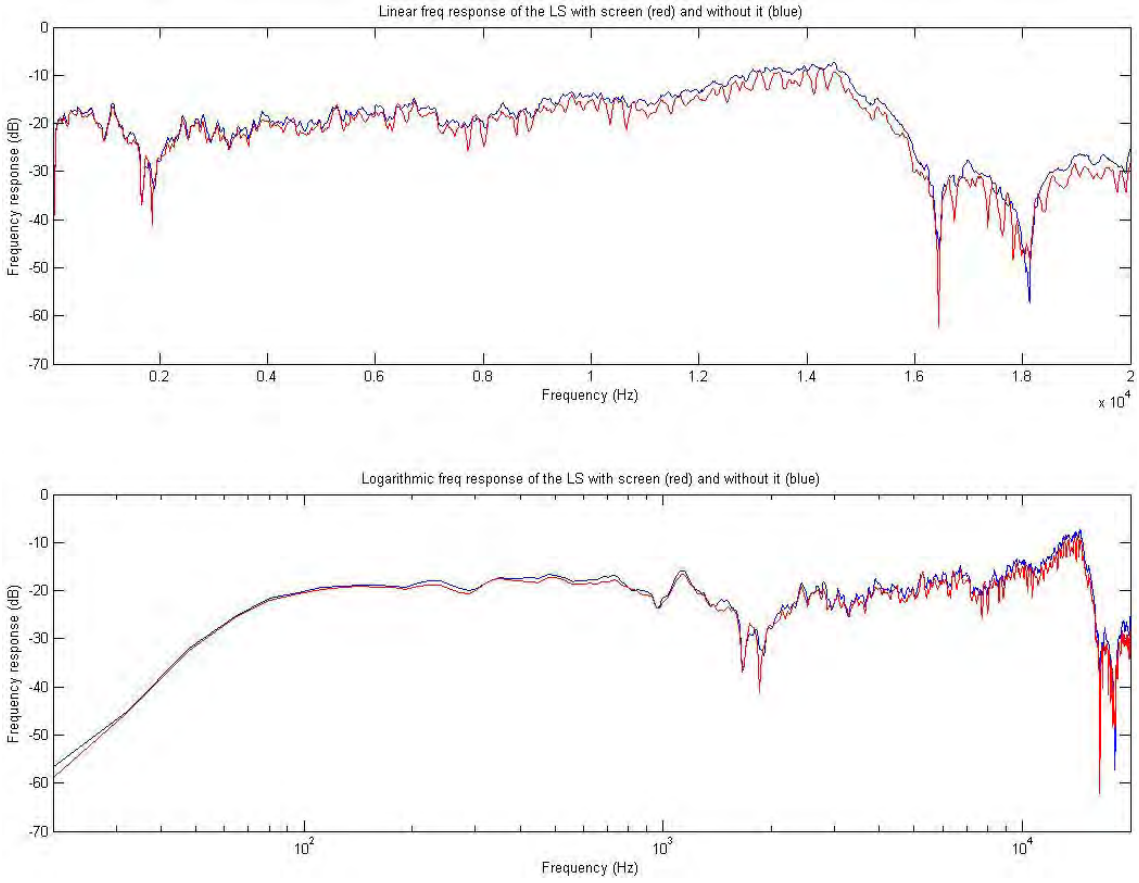

Fig. A. 23: Freq. response for screen Enlightor 4K at a distance of 60cm. 30 degrees

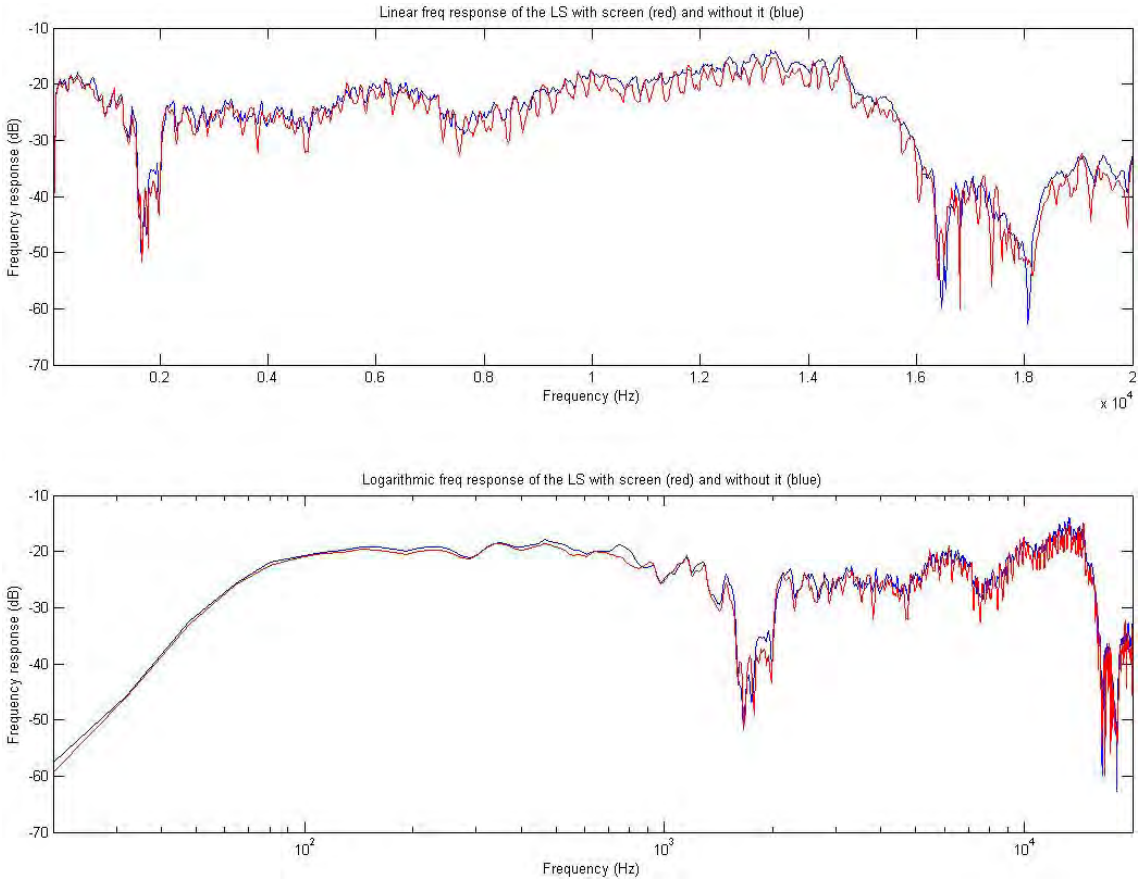

Fig. A. 24: Freq. response for screen Enlightor 4K at a distance of 60cm. 45 degrees

Frequency response for screen Enlightor 4K with screen angled 10 degrees.

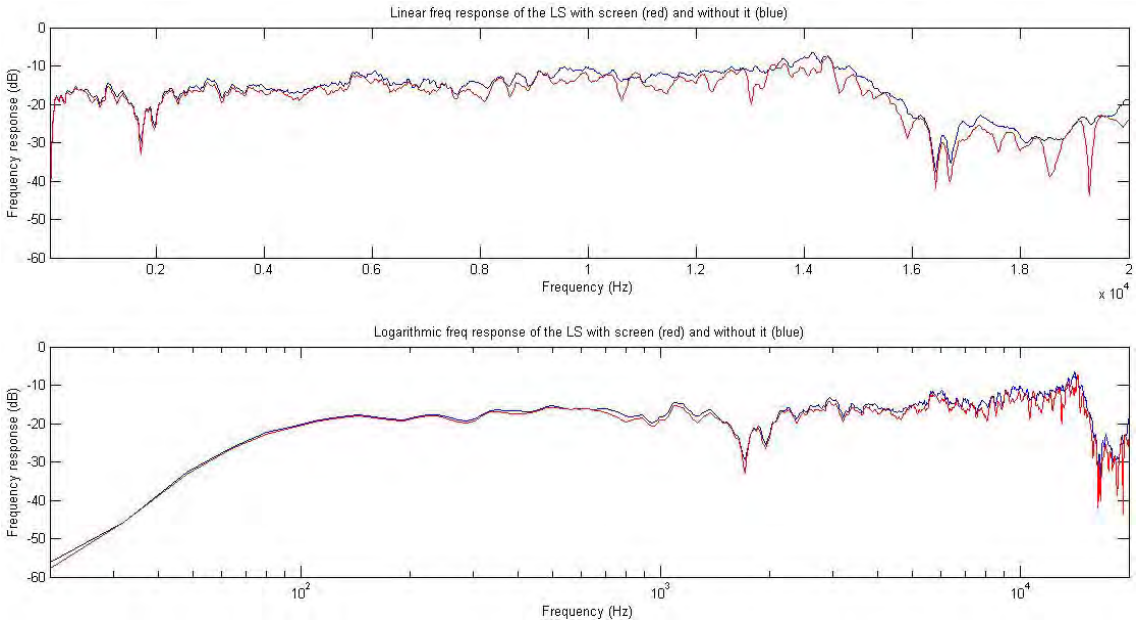

Fig. A. 25: Frequency response for screen Enlightor 4K with screen angled 10 degrees. Mic position 0 degrees

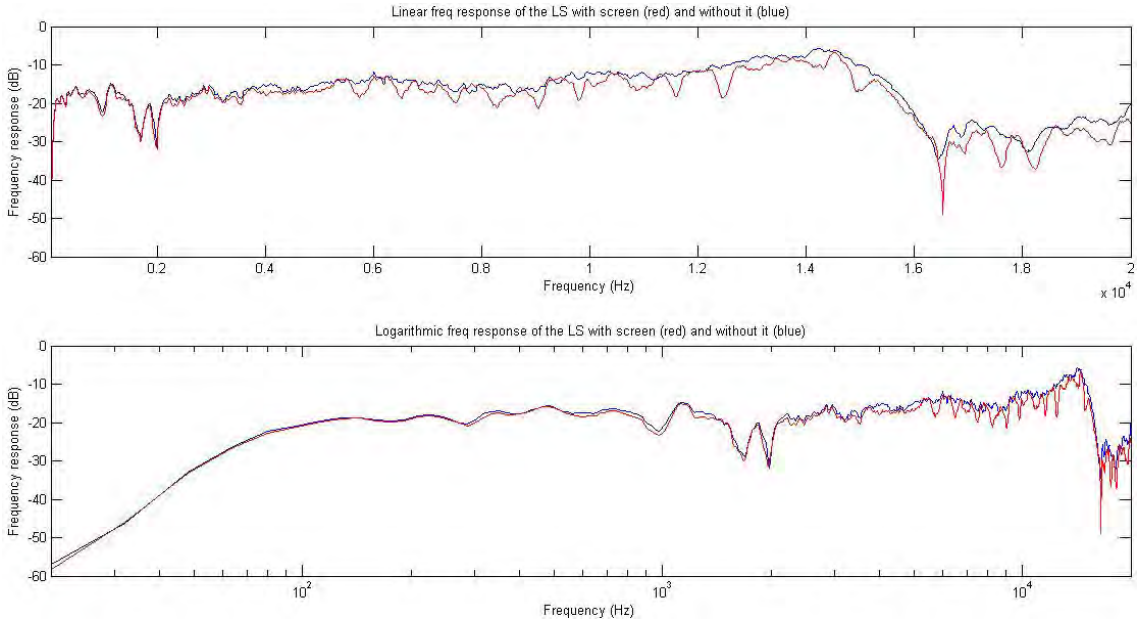

Fig. A. 26: Frequency response for screen Enlightor 4K with screen angled 10 degrees. Mic position 15 degrees

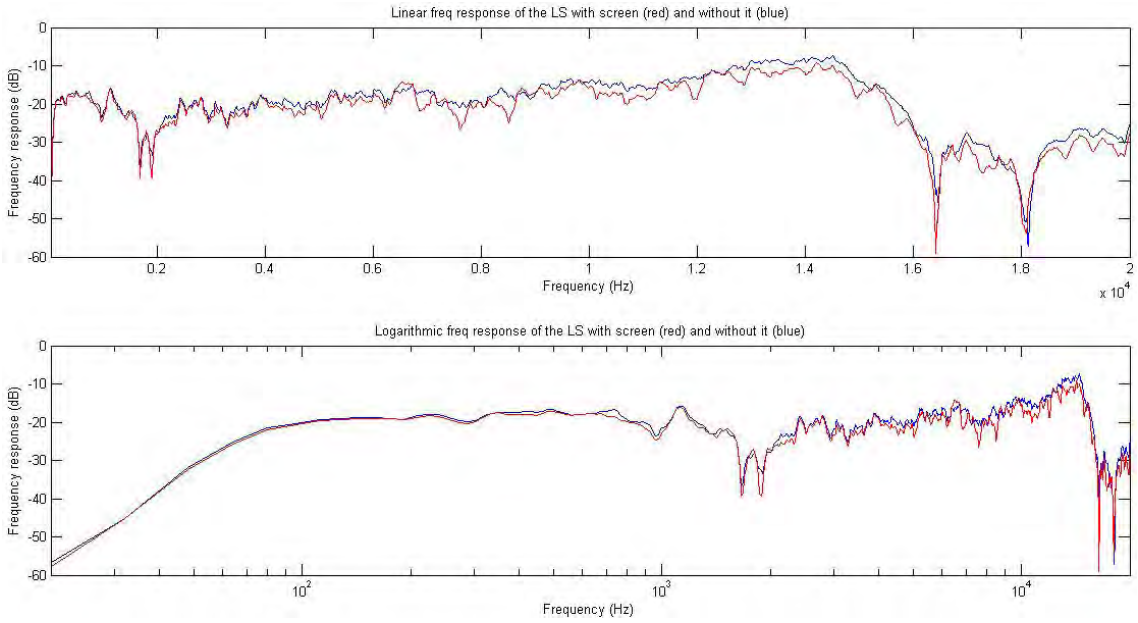

Fig. A. 27: Frequency response for screen Enlightor 4K with screen angled 10 degrees. Mic position 30 degrees

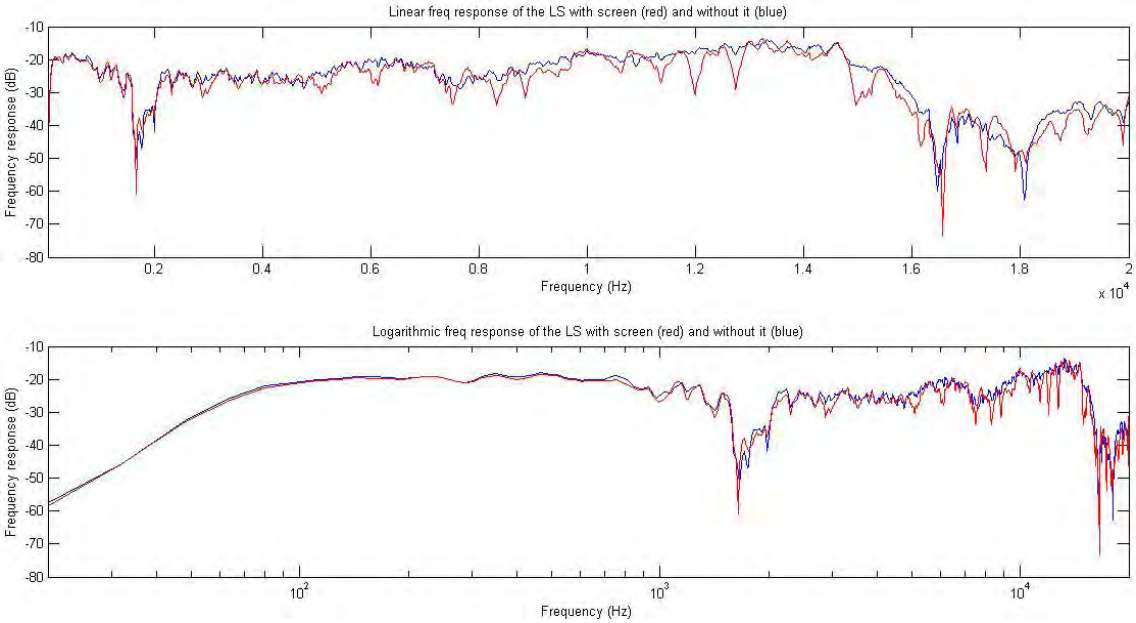

Fig. A. 28: Frequency response for screen Enlightor 4K with screen angled 10 degrees. Mic position 45 degrees

Frequency response for screen Enlightor 4K with screen angled 25 degrees

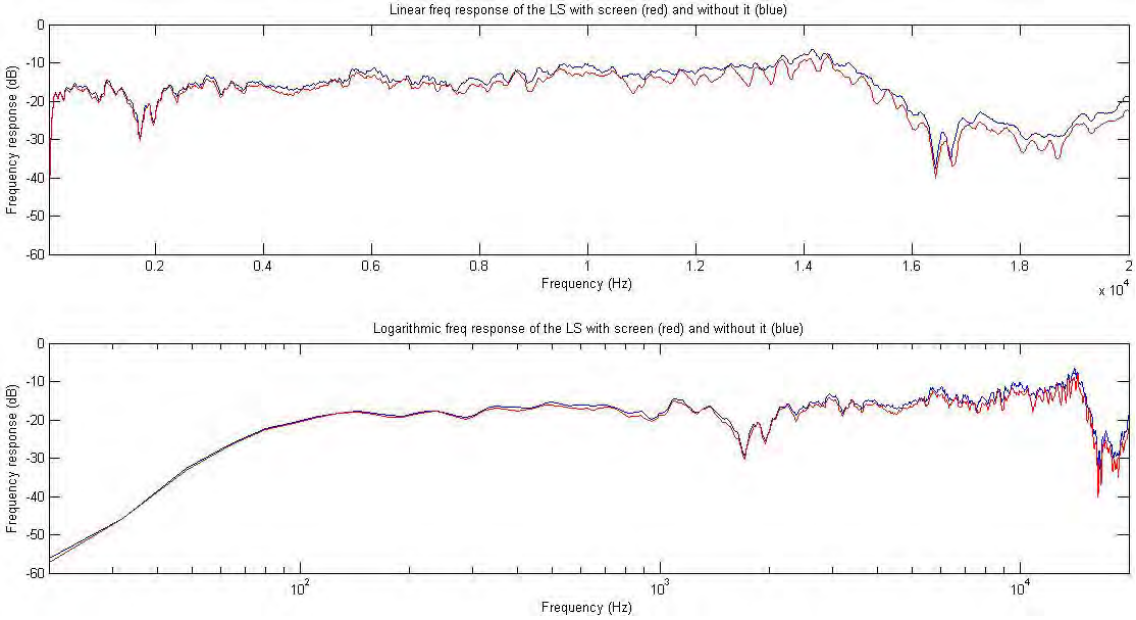

Fig. A. 29: Frequency response for screen Enlightor 4K with screen angled 25 degrees. Mic position 0 degrees

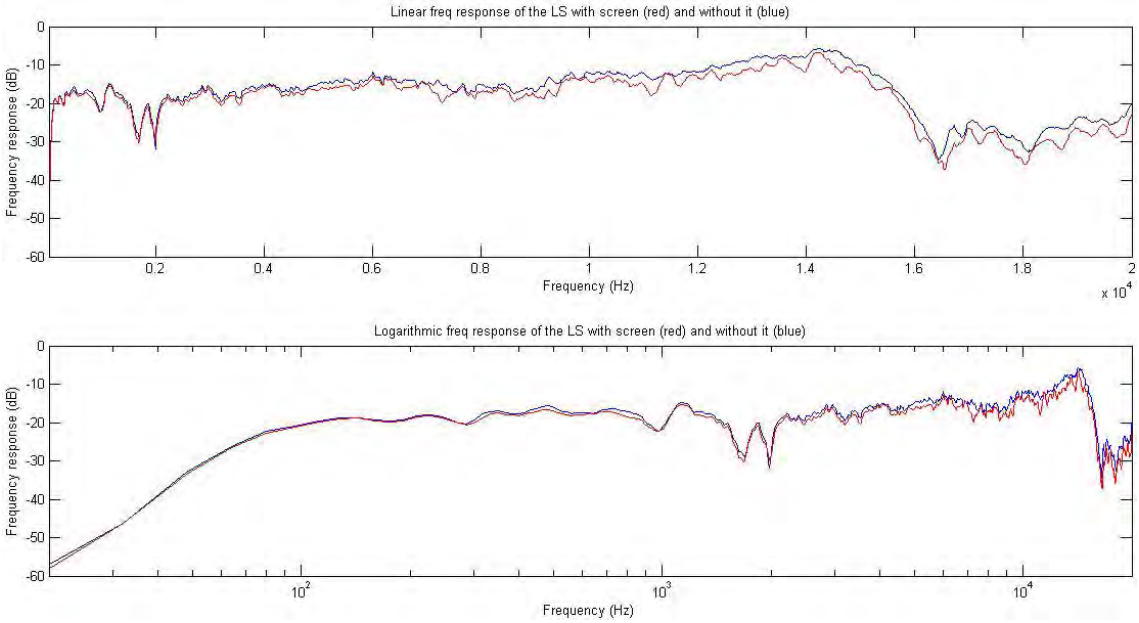

Fig. A. 30: Frequency response for screen Enlightor 4K with screen angled 25 degrees. Mic position 15 degrees

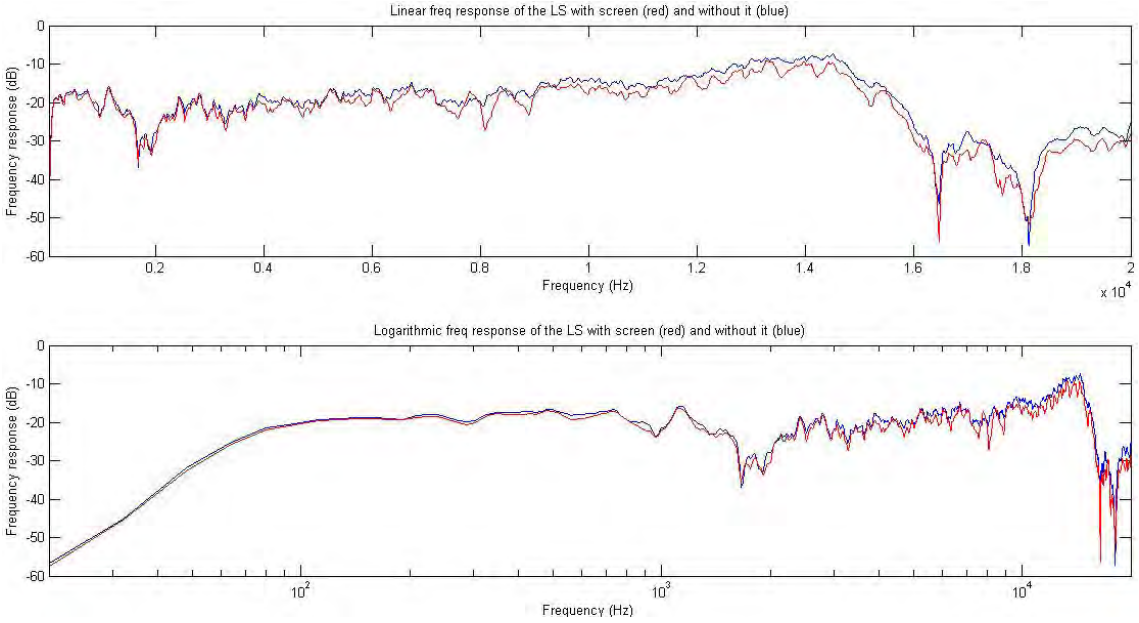

Fig. A. 31: Frequency response for screen Enlightor 4K with screen angled 25 degrees. Mic position 30 degrees

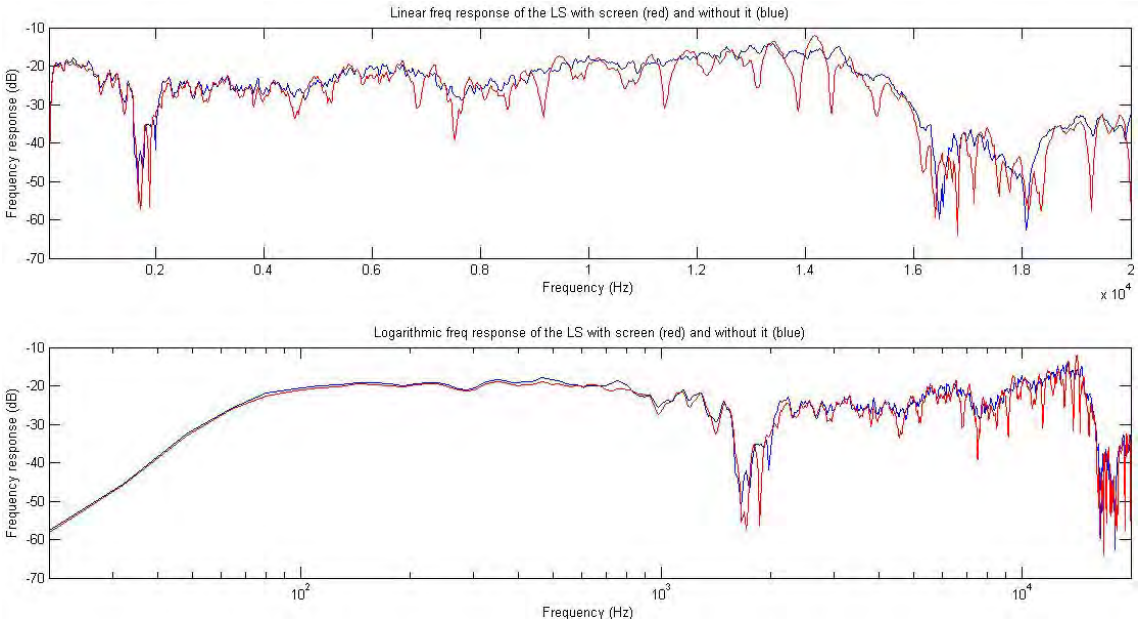

Fig. A. 32: Frequency response for screen Enlightor 4K with screen angled 25 degrees. Mic position 45 degrees

A. 2. Matt Plus Miniperforated

Frequency response for screen Matt Plus Miniperforated at a distance of 2 cm

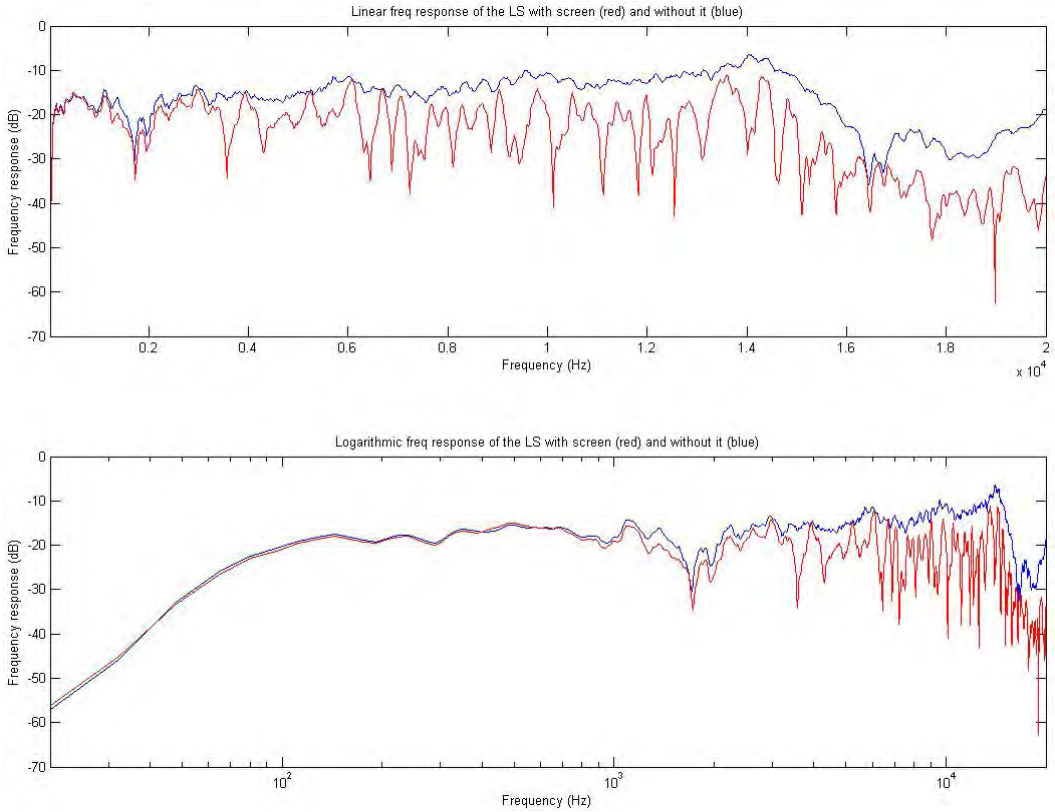

Fig. A. 33: Freq. response for screen Matt Plus Miniperforated at a distance of 2 cm. 0 degrees

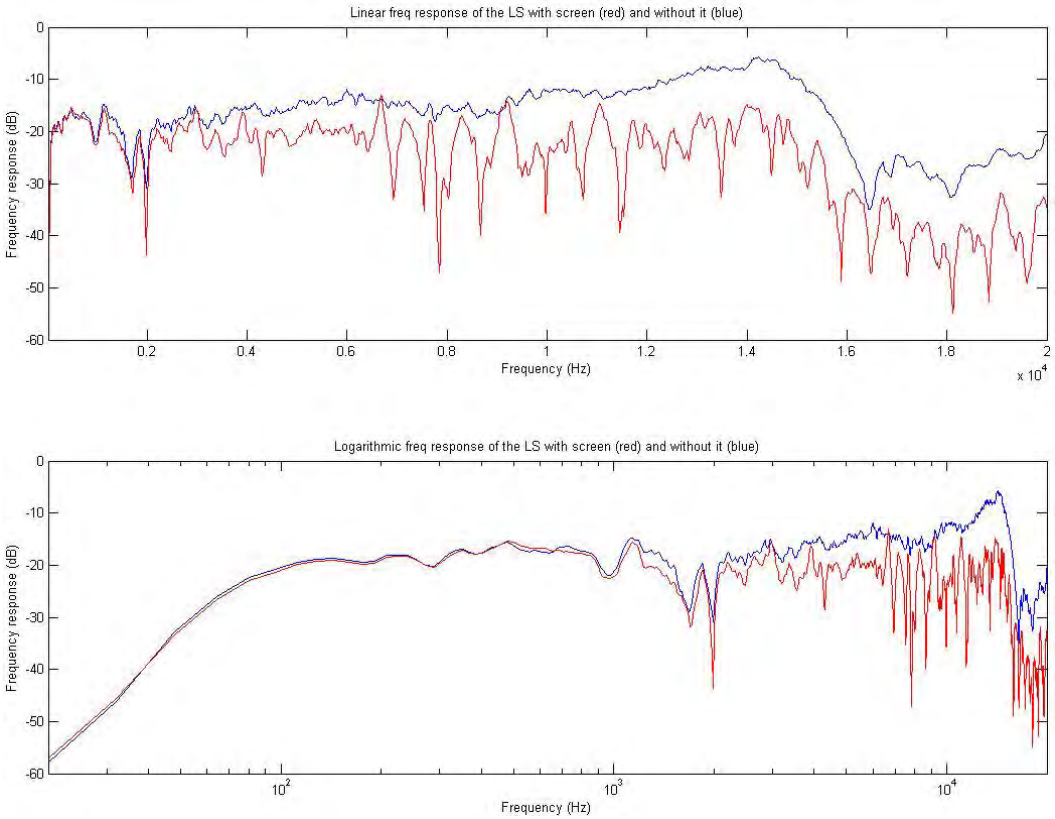

Fig. A. 34: Freq. response for screen Matt Plus Miniperforated at a distance of 2 cm. 15 degrees

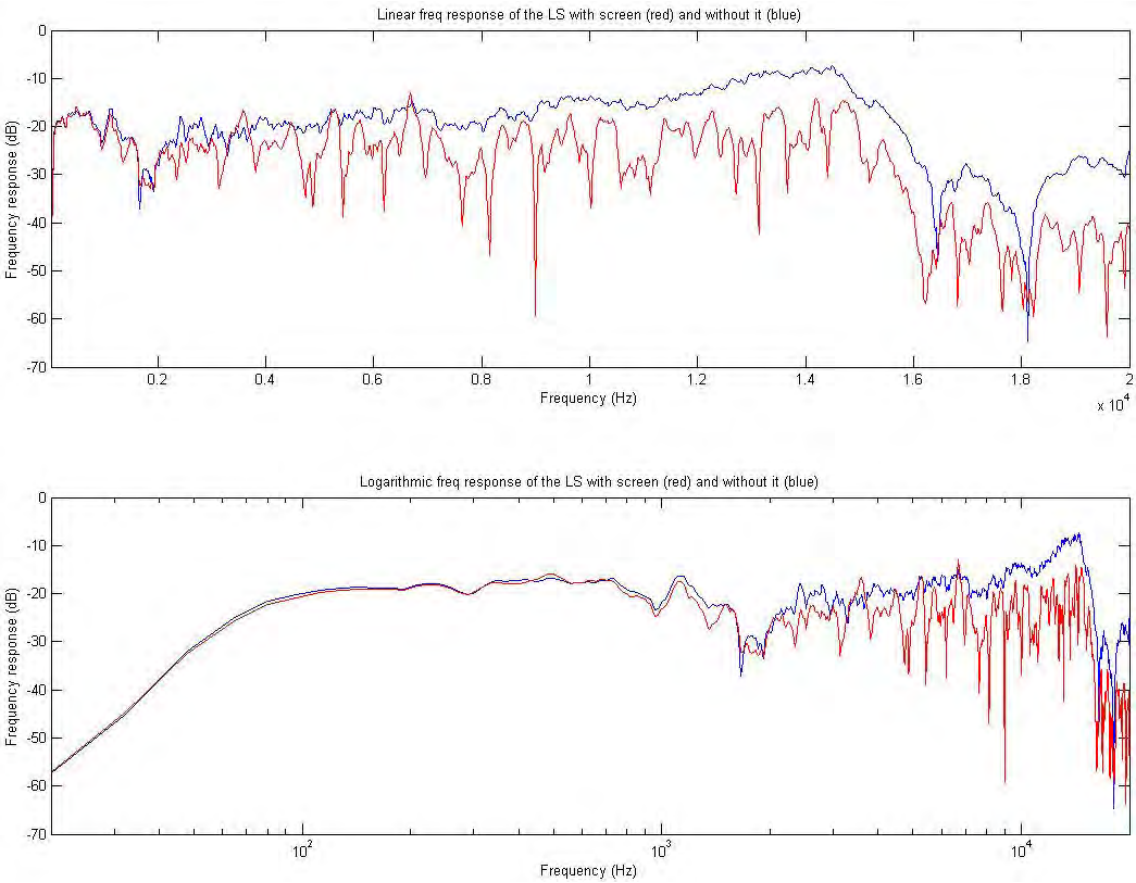

Fig. A. 35: Freq. response for screen Matt Plus Miniperforated at a distance of 2 cm. 30 degrees

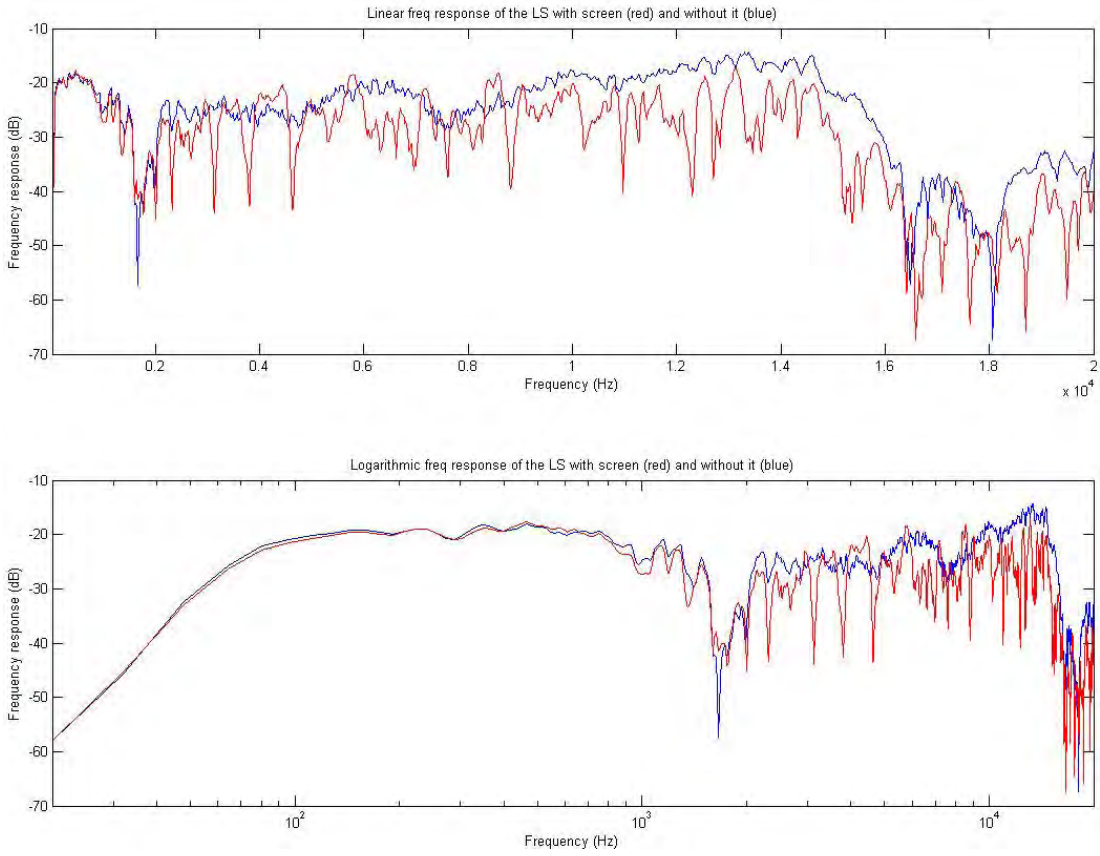

Fig. A. 36: Freq. response for screen Matt Plus Miniperforated at a distance of 2 cm. 45 degrees

Frequency response for screen Matt Plus Miniperforated at a distance of 7 cm

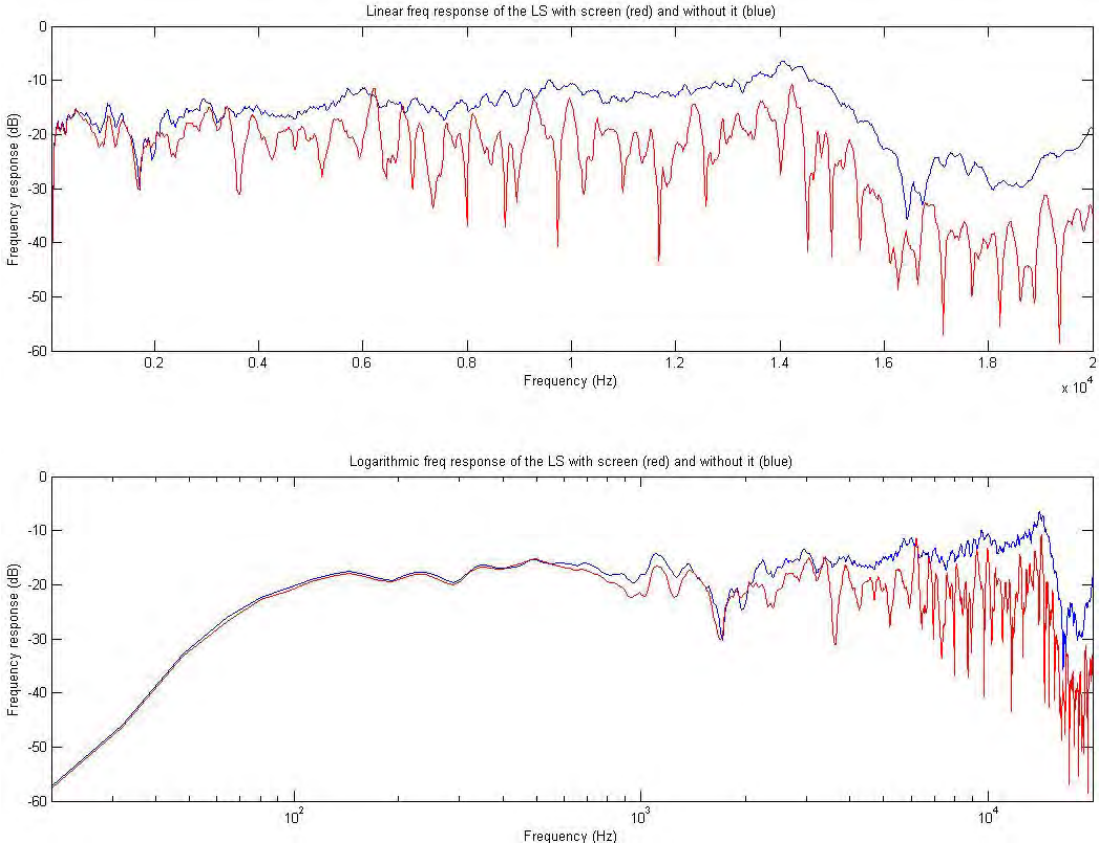

Fig. A. 37: Freq. response for screen Matt Plus Miniperforated at a distance of 7 cm. 0 degrees

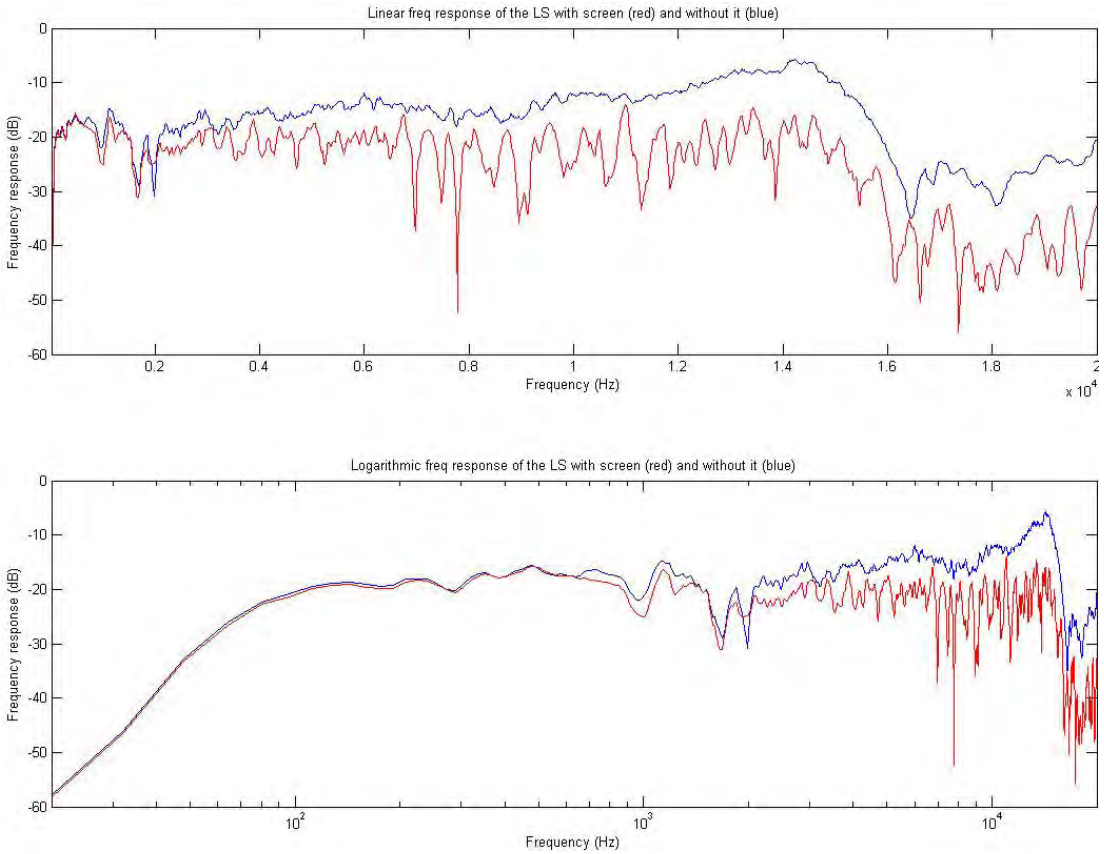

Fig. A. 38: Freq. response for screen Matt Plus Miniperforated at a distance of 7 cm. 15 degrees

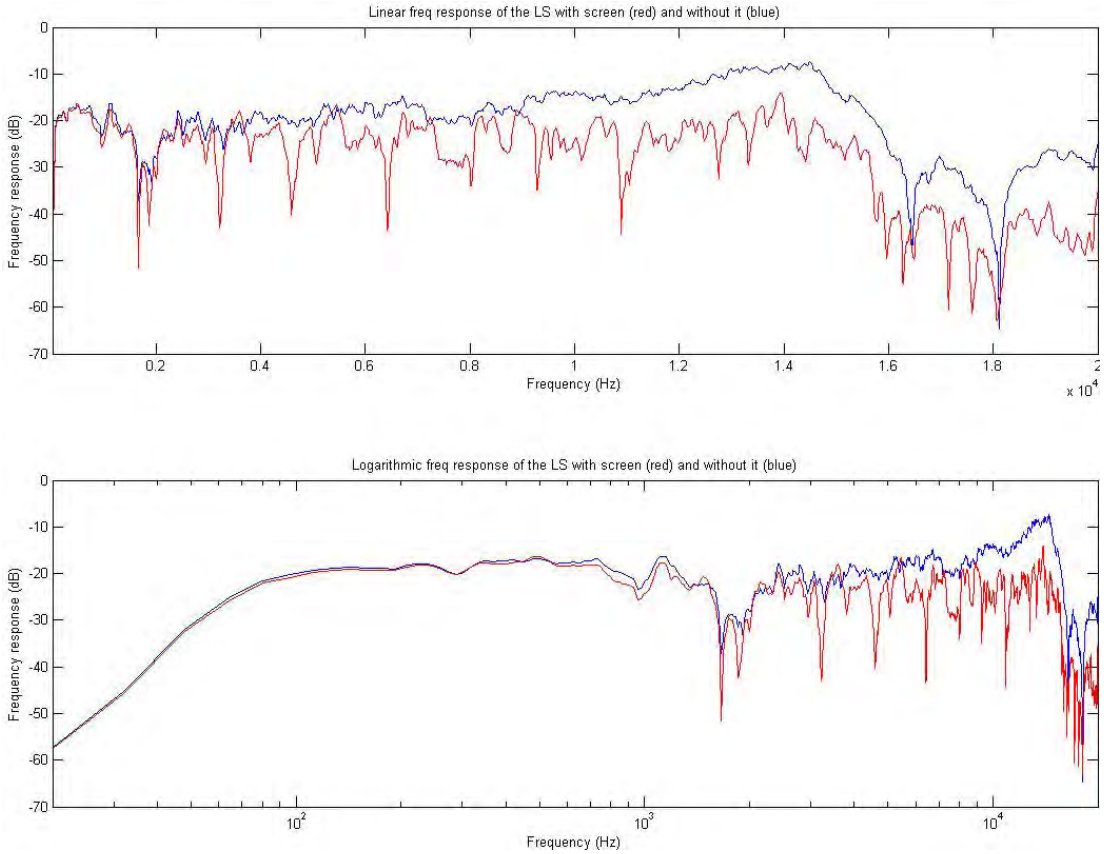

Fig. A. 39: Freq. response for screen Matt Plus Miniperforated at a distance of 7 cm. 30 degrees

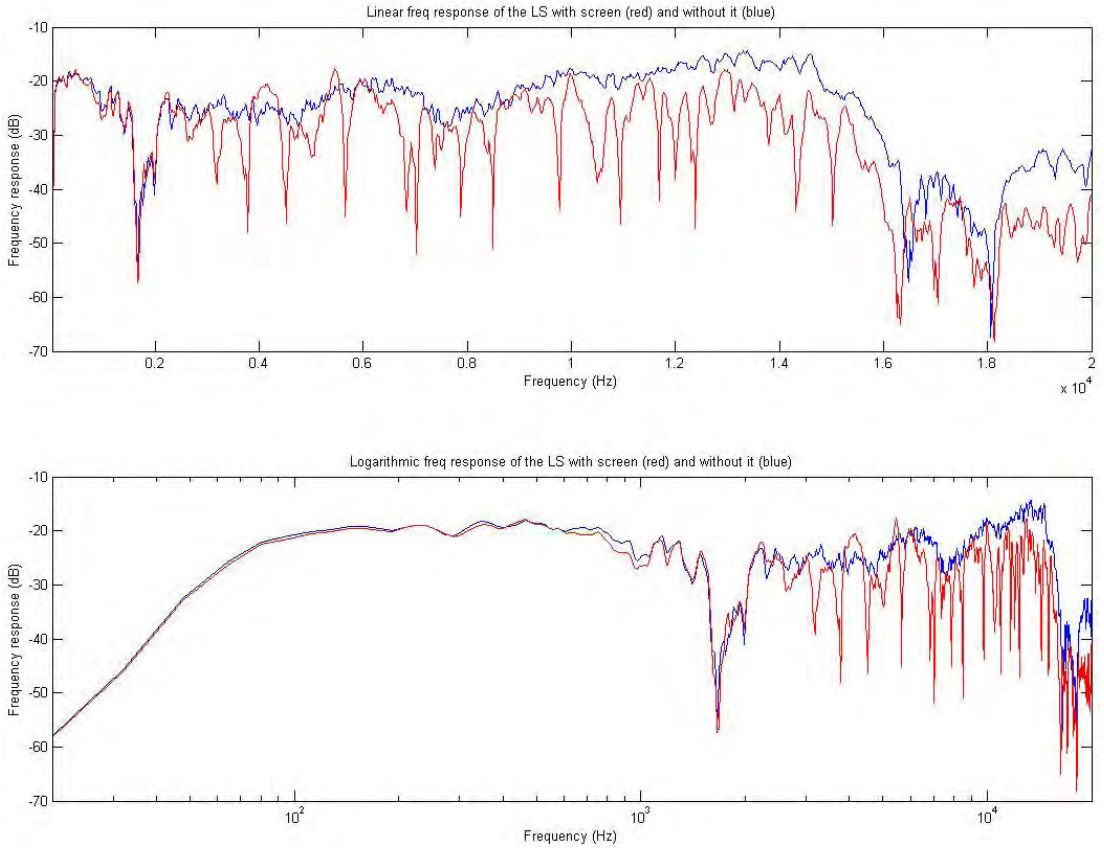

Fig. A. 40: Freq. response for screen Matt Plus Miniperforated at a distance of 7 cm. 45 degrees

Frequency response for screen Matt Plus Miniperforated at a distance of 15 cm

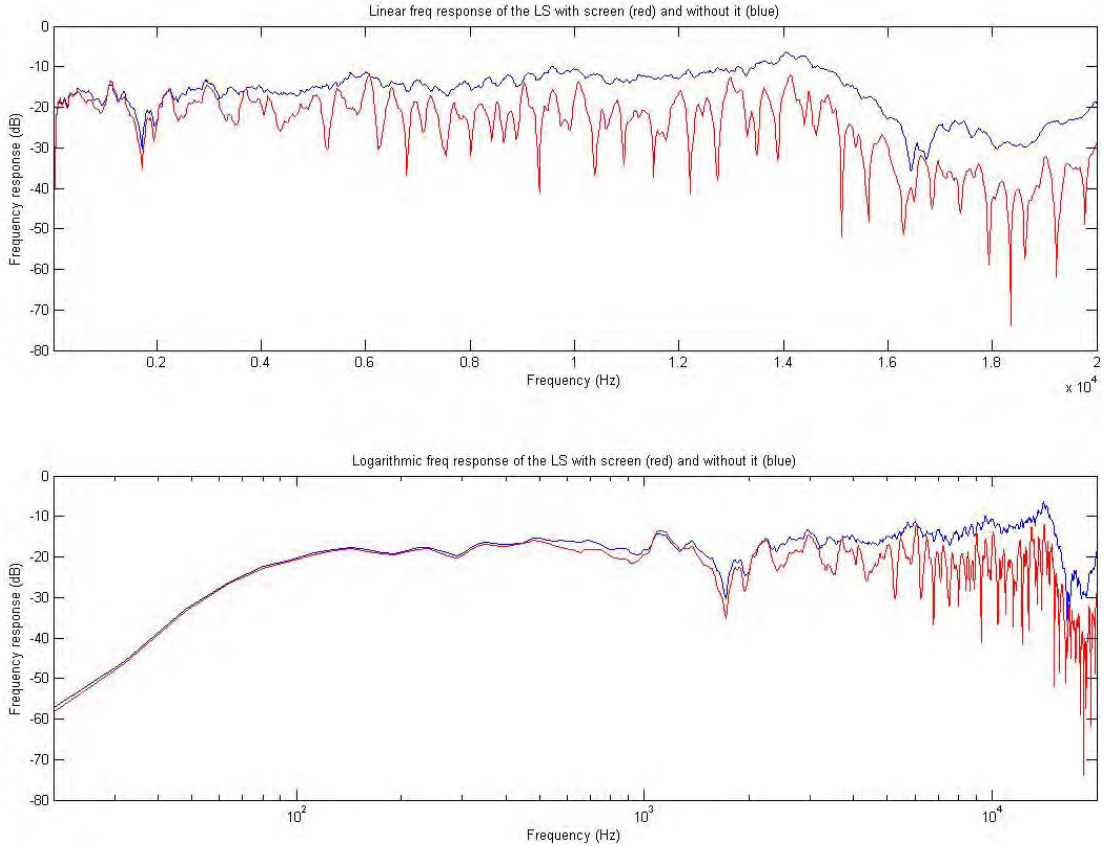

Fig. A. 41: Freq. response for screen Matt Plus Miniperforated at a distance of 15 cm. 0 degrees

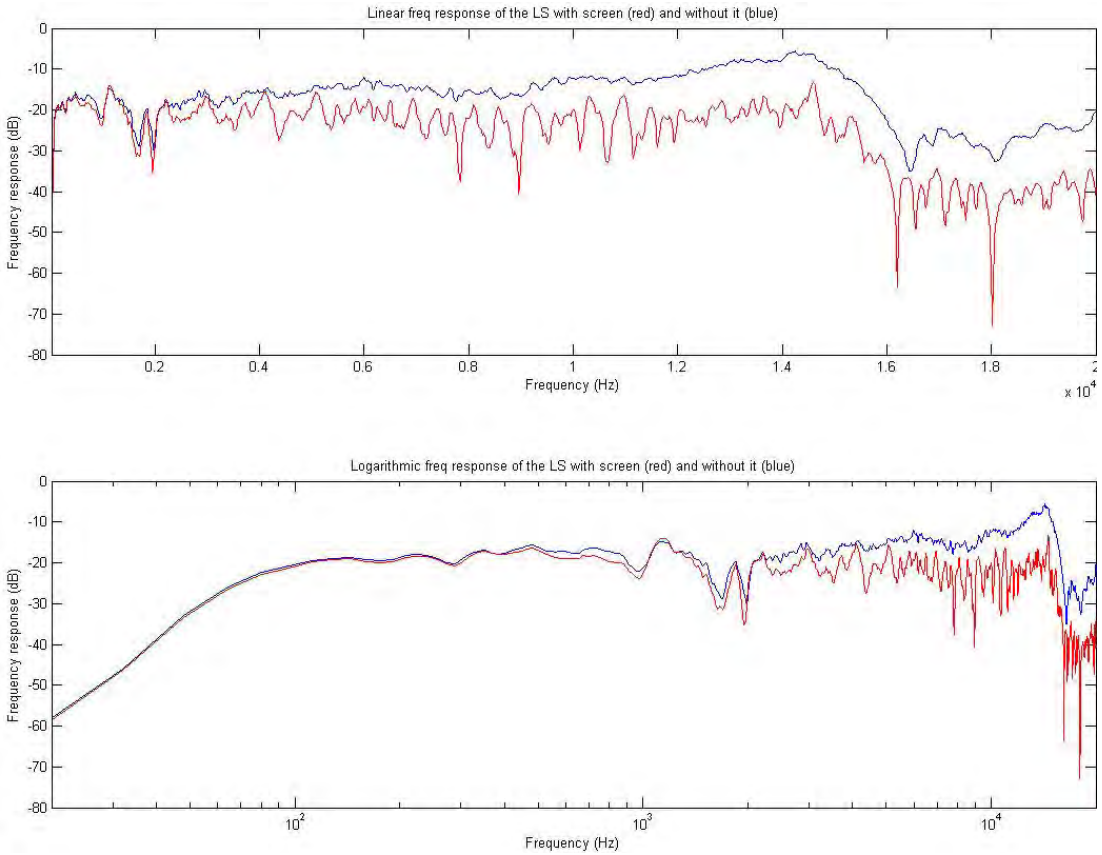

Fig. A. 42: Freq. response for screen Matt Plus Miniperforated at a distance of 15 cm. 15 degrees

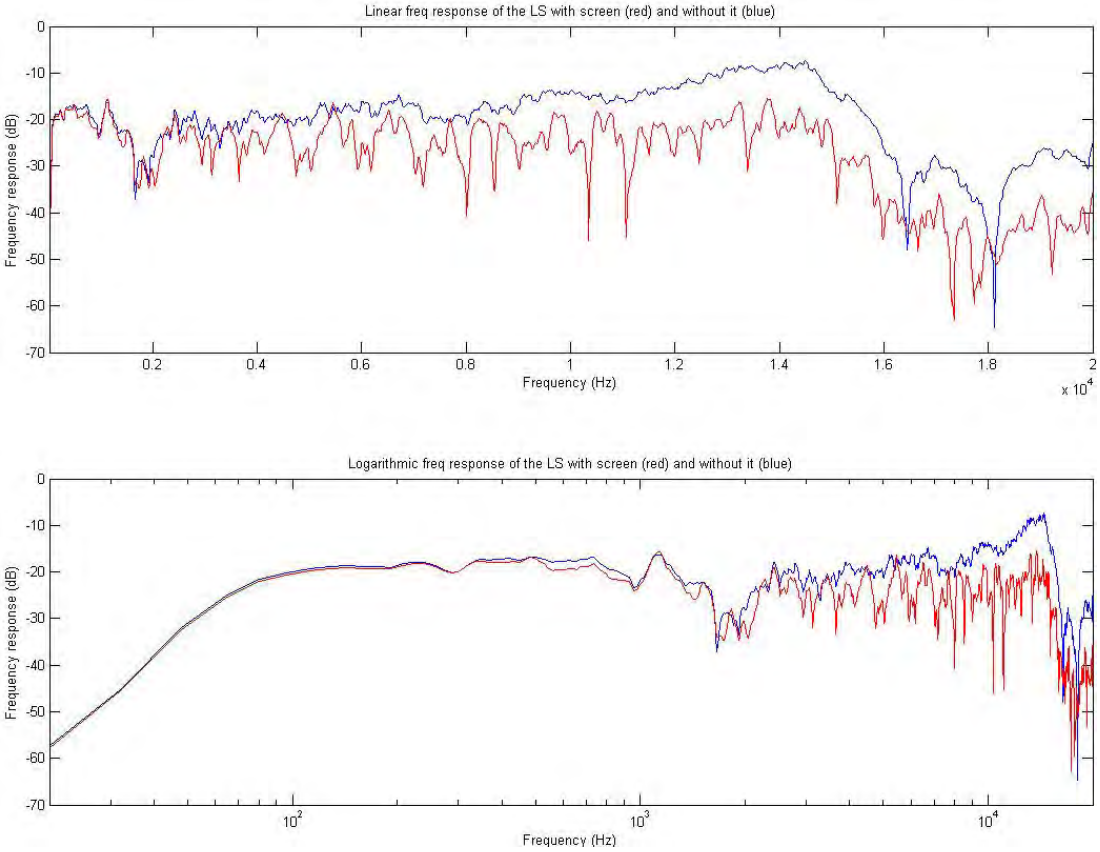

Fig. A. 43: Freq. response for screen Matt Plus Miniperforated at a distance of 15 cm. 30 degrees

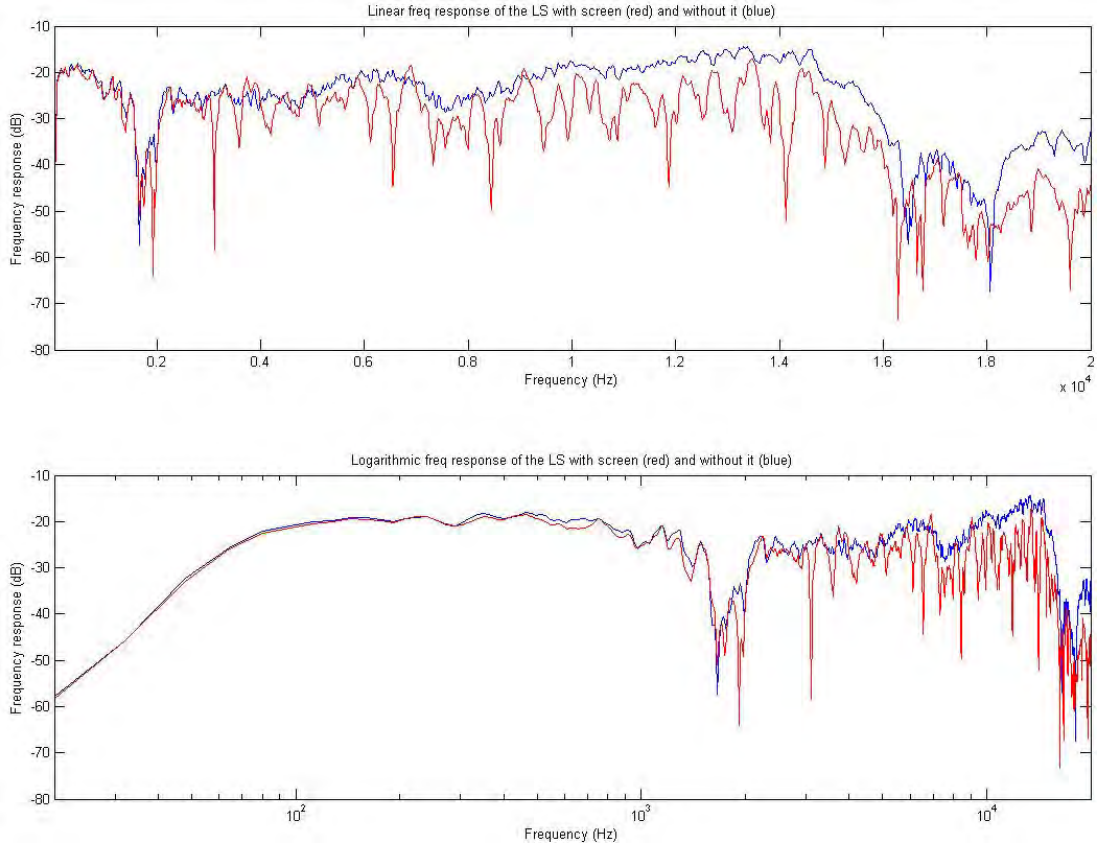

Fig. A. 44: Freq. response for screen Matt Plus Miniperforated at a distance of 15 cm. 45 degrees

Frequency response for screen Matt Plus Miniperforated at a distance of 30 cm

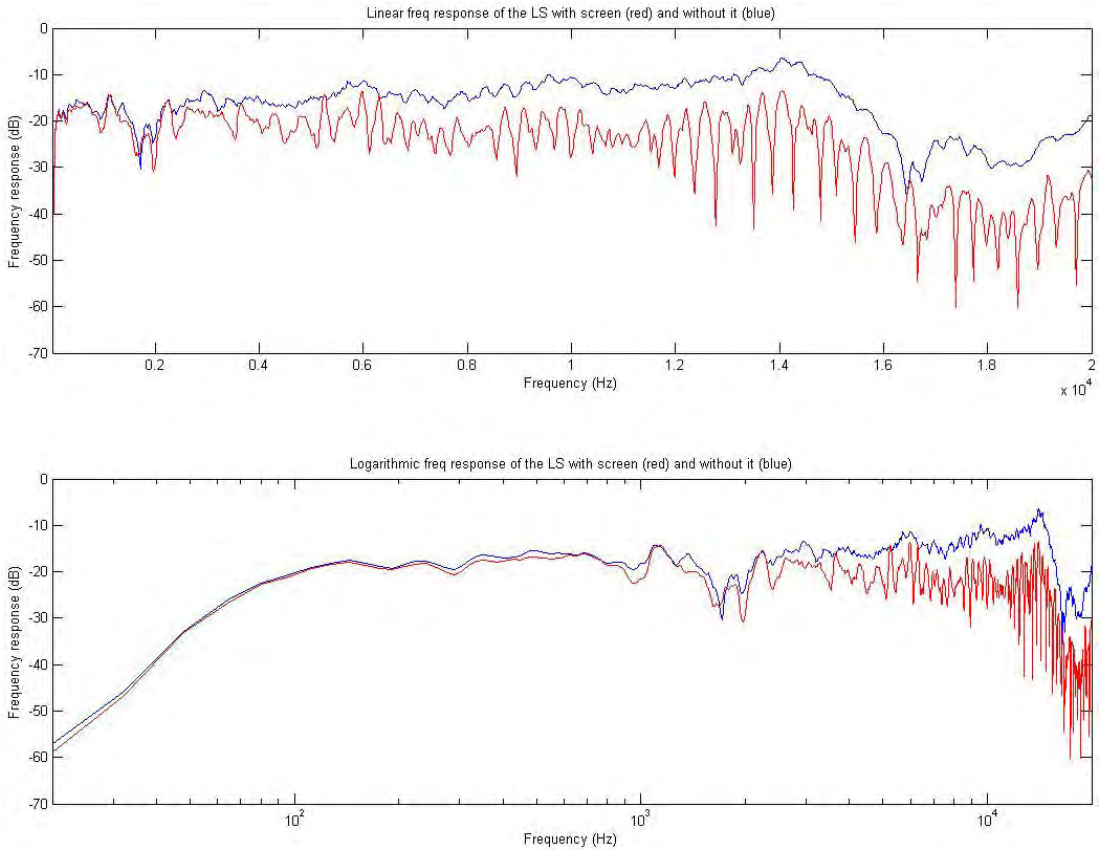

Fig. A. 45: Freq. response for screen Matt Plus Miniperforated at a distance of 30 cm. 0 degrees

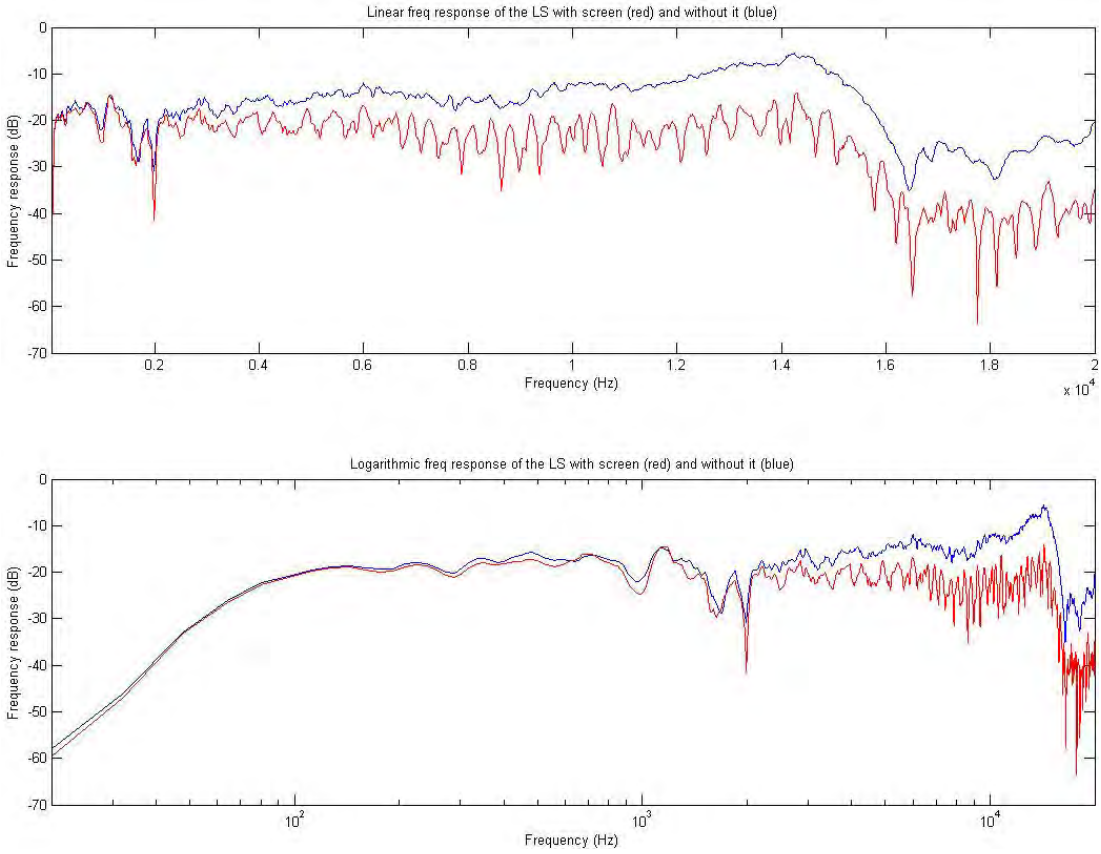

Fig. A. 46: Freq. response for screen Matt Plus Miniperforated at a distance of 30 cm. 15 degrees

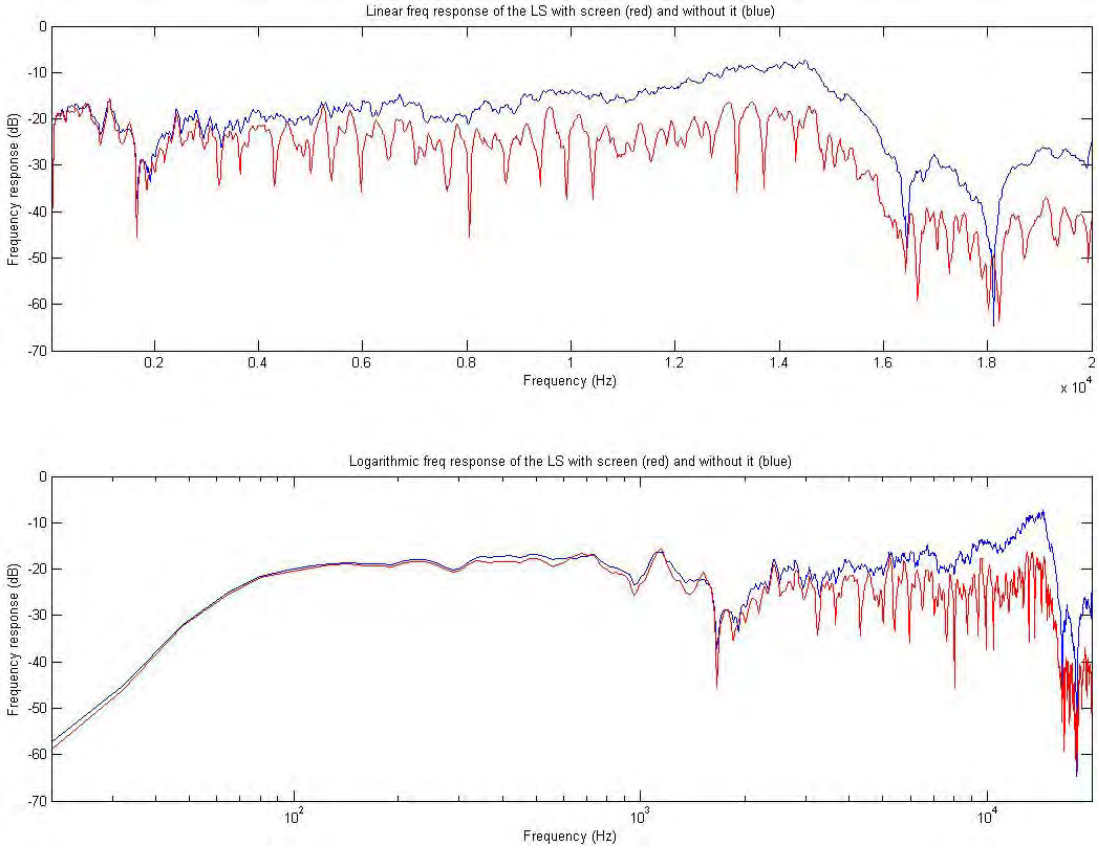

Fig. A. 47: Freq. response for screen Matt Plus Miniperforated at a distance of 30 cm. 30 degrees

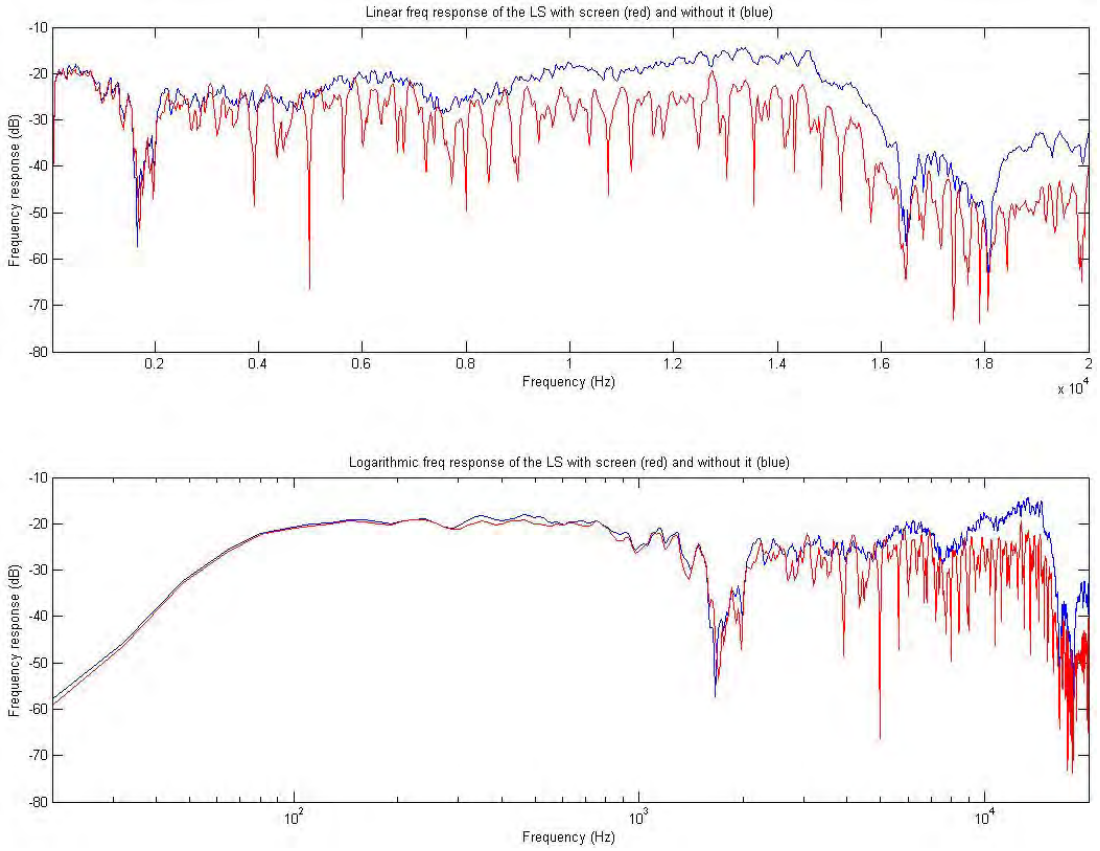

Fig. A. 48: Freq. response for screen Matt Plus Miniperforated at a distance of 30 cm. 45 degrees

Frequency response for screen Matt Plus Miniperforated at a distance of 45 cm

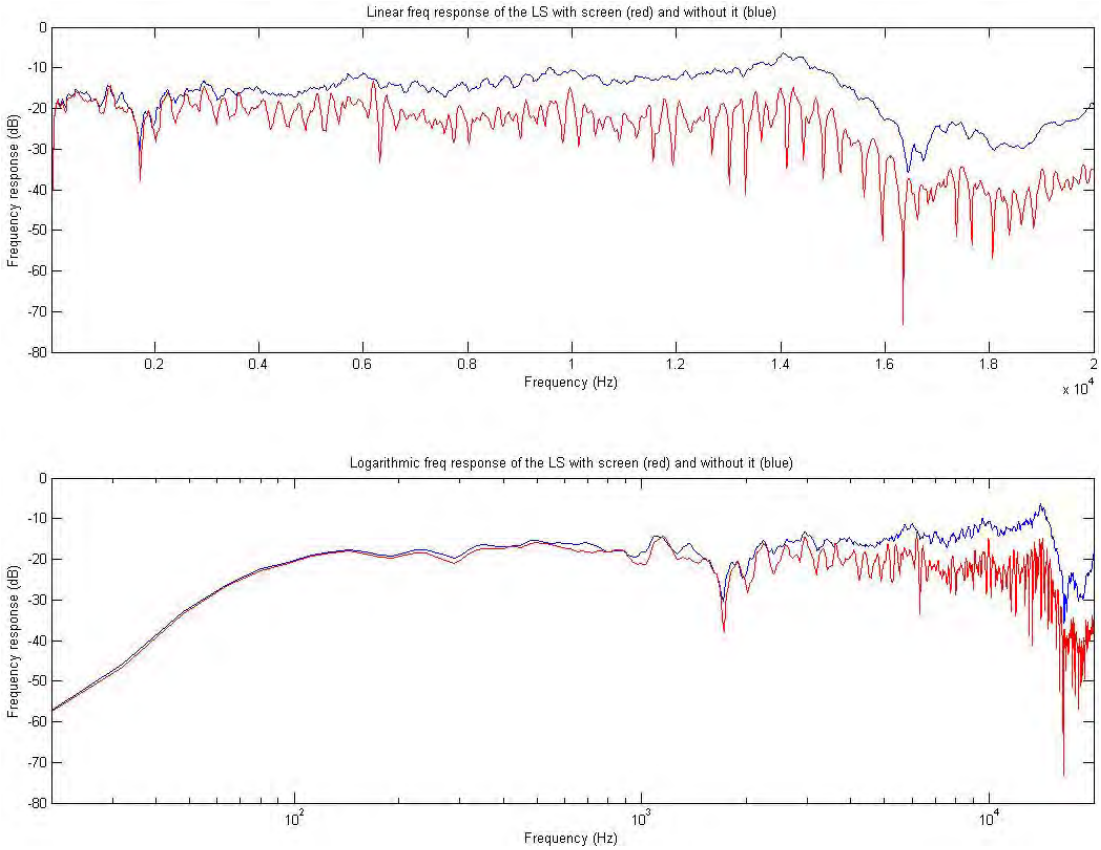

Fig. A. 49: Freq. response for screen Matt Plus Miniperforated at a distance of 45 cm. 0 degrees

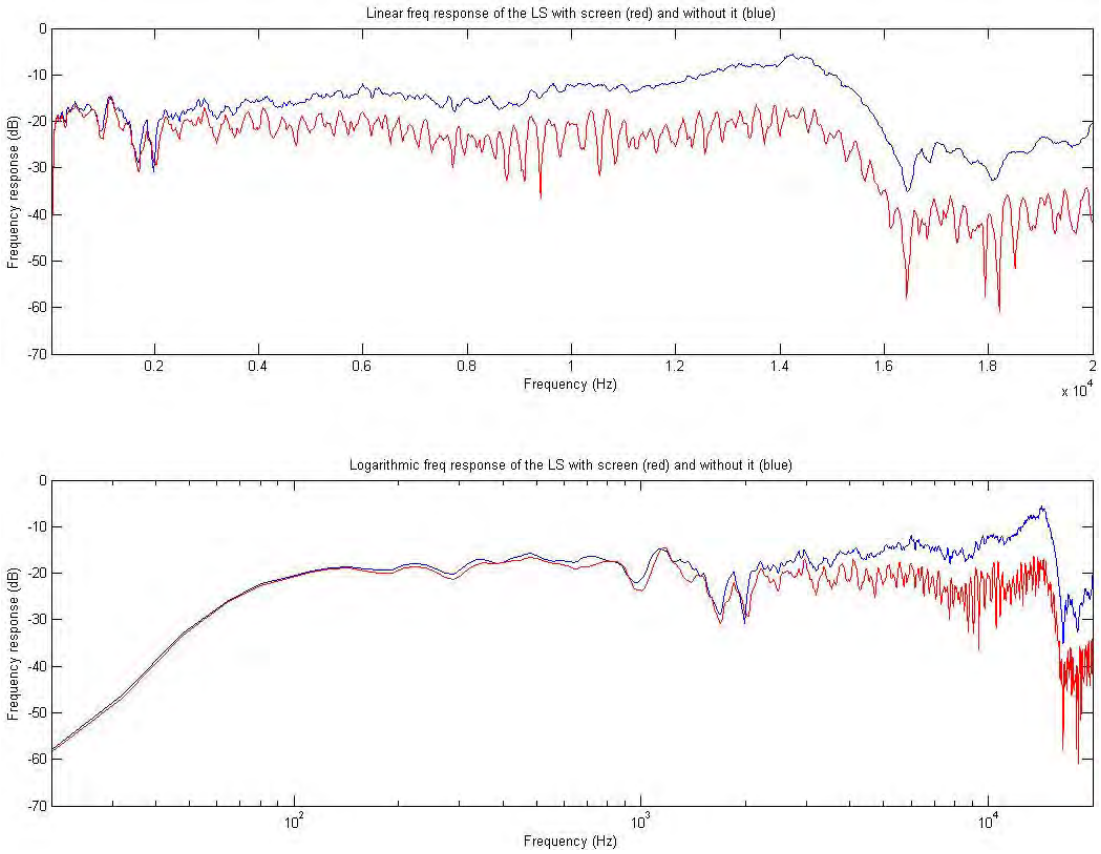

Fig. A. 50: Freq. response for screen Matt Plus Miniperforated at a distance of 45 cm. 15 degrees

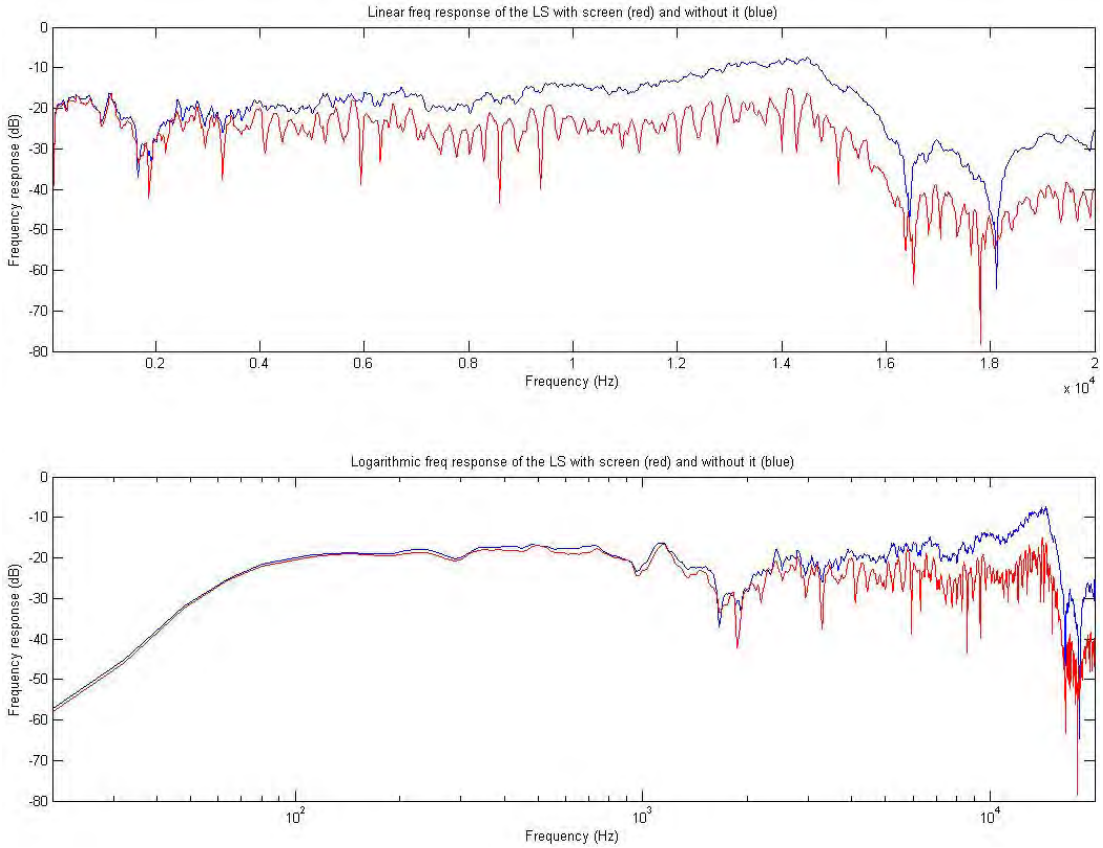

Fig. A. 51: Freq. response for screen Matt Plus Miniperforated at a distance of 45 cm. 30 degrees

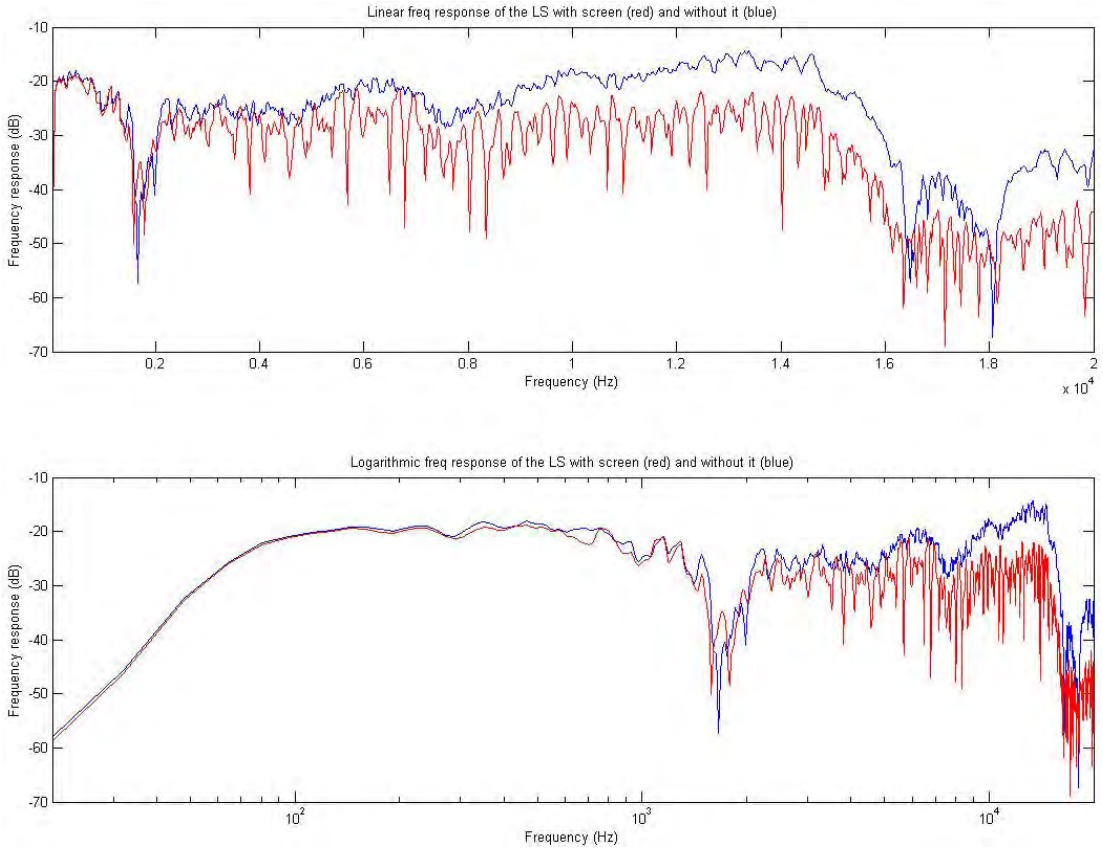

Fig. A. 52: Freq. response for screen Matt Plus Miniperforated at a distance of 45 cm. 45 degrees

Frequency response for screen Matt Plus Miniperforated at a distance of 60 cm

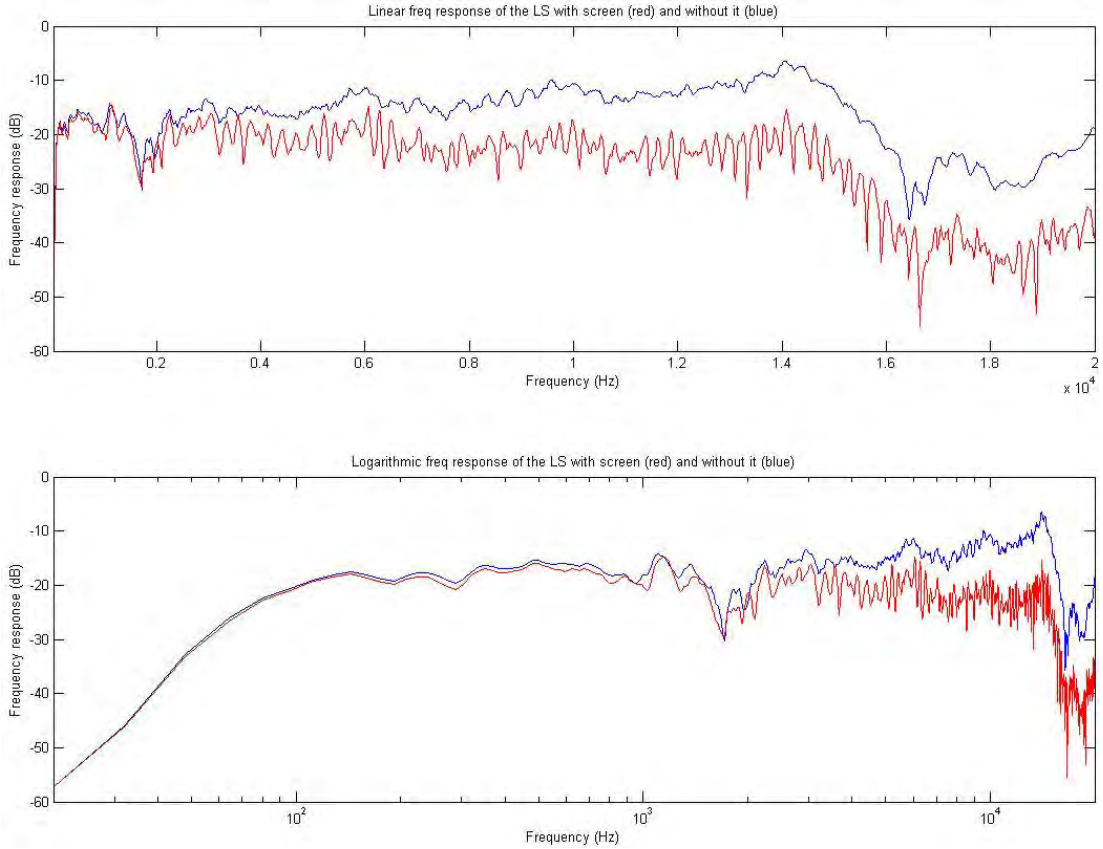

Fig. A. 53: Freq. response for screen Matt Plus Miniperforated at a distance of 60 cm. 0 degrees

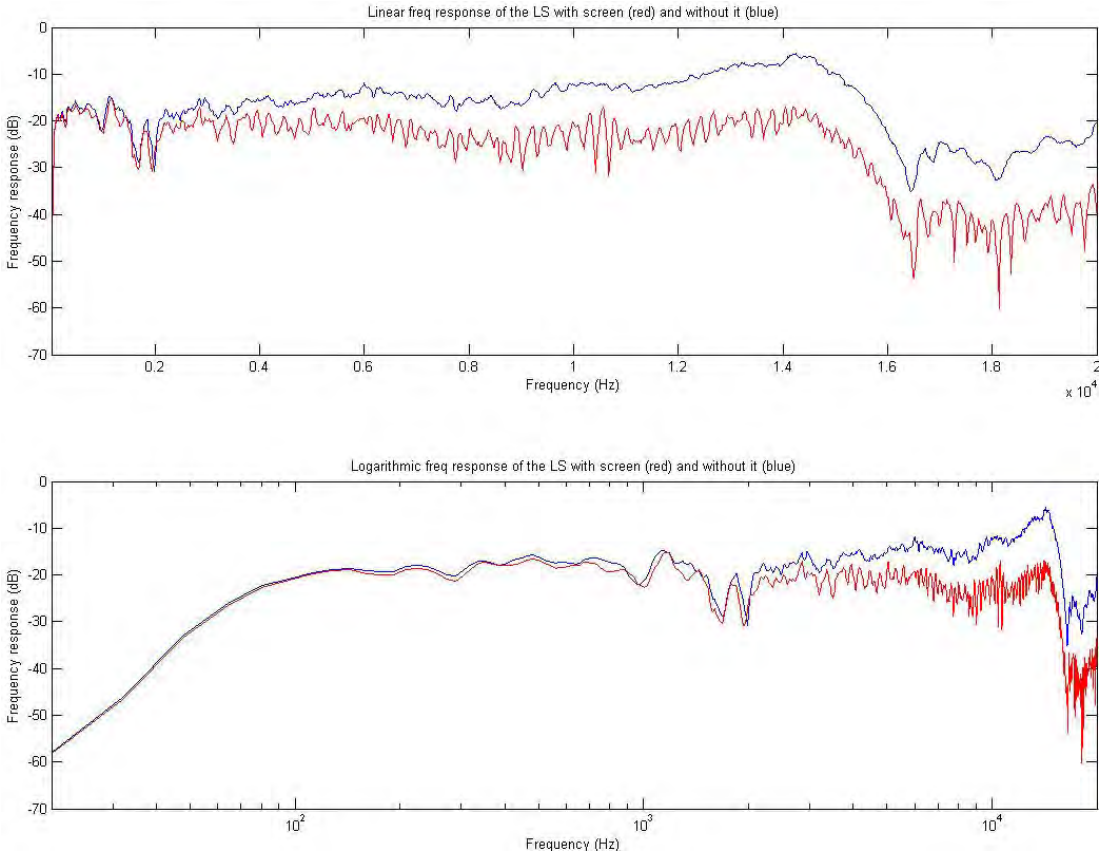

Fig. A. 54: Freq. response for screen Matt Plus Miniperforated at a distance of 60 cm. 15 degrees

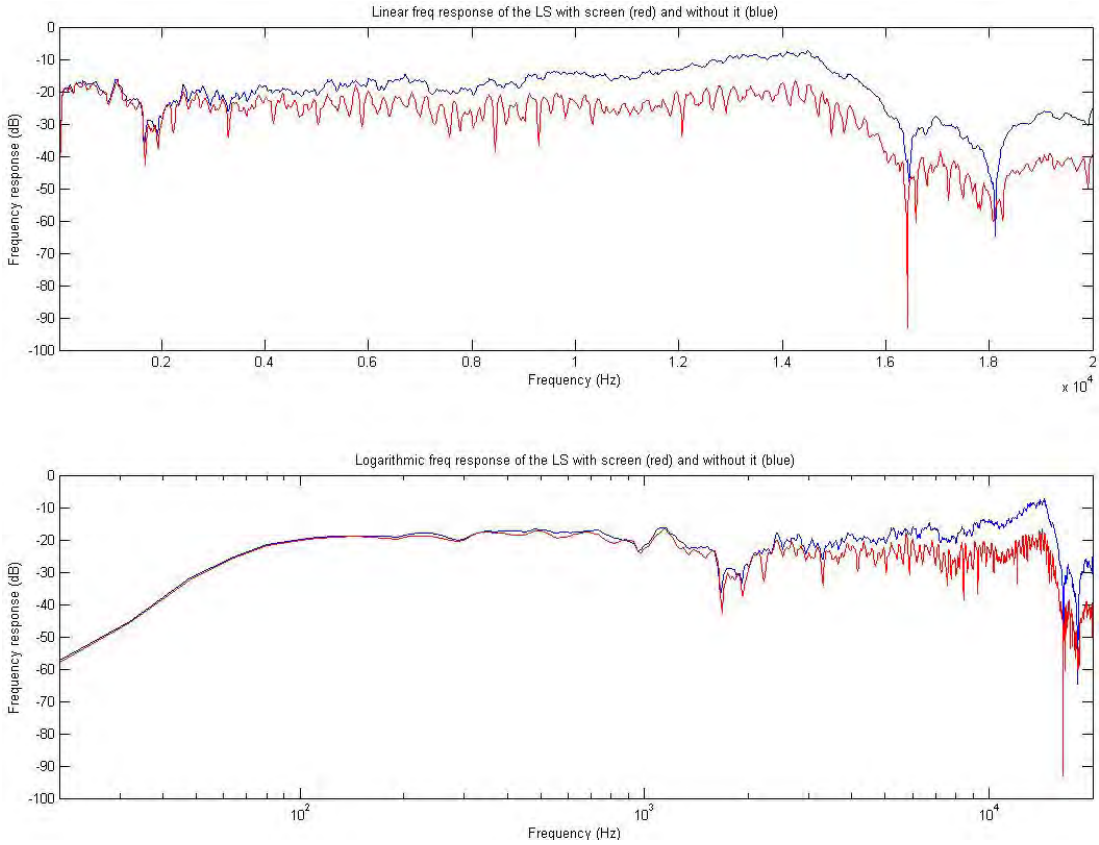

Fig. A. 55: Freq. response for screen Matt Plus Miniperforated at a distance of 60 cm. 30 degrees

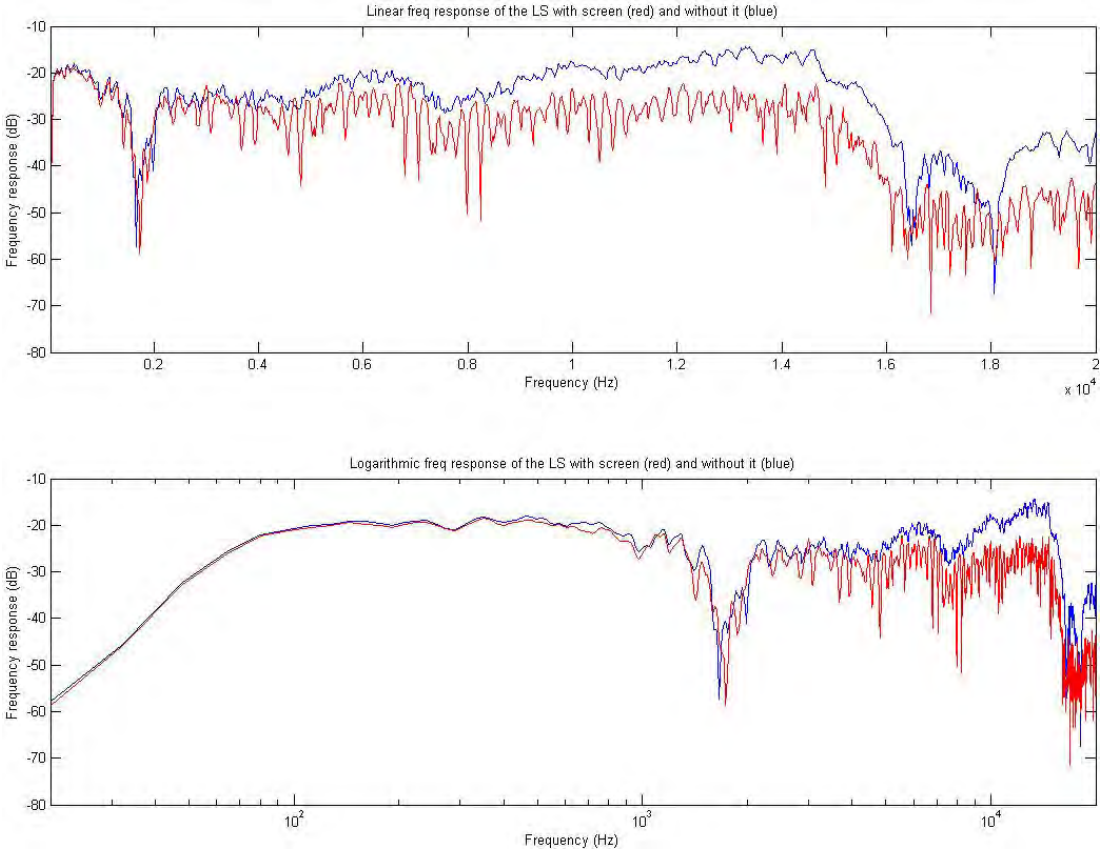

Fig. A. 56: Freq. response for screen Matt Plus Miniperforated at a distance of 60 cm. 45 degrees

Frequency response for Matt Plus Miniperforated with screen angled 10 degrees

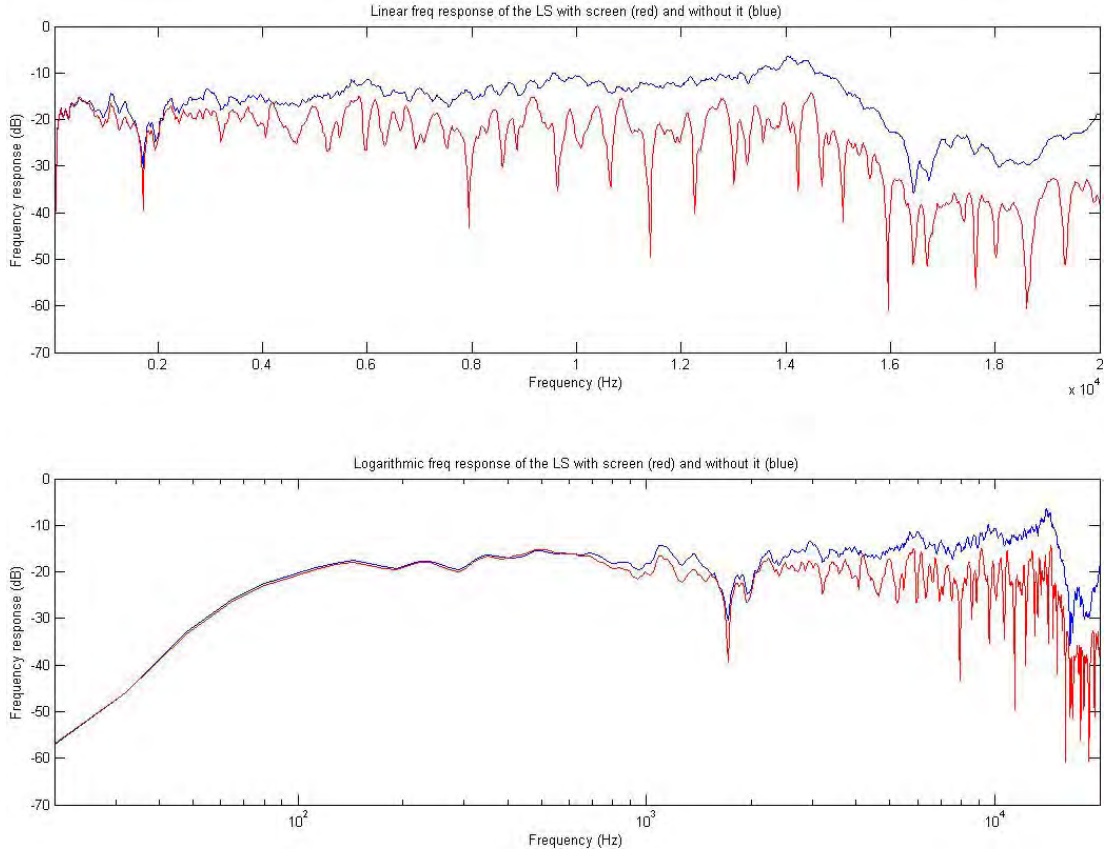

Fig. A. 57: Freq. response for Matt Plus Miniperforated with screen angled 10 degrees. Mic position 0 deg

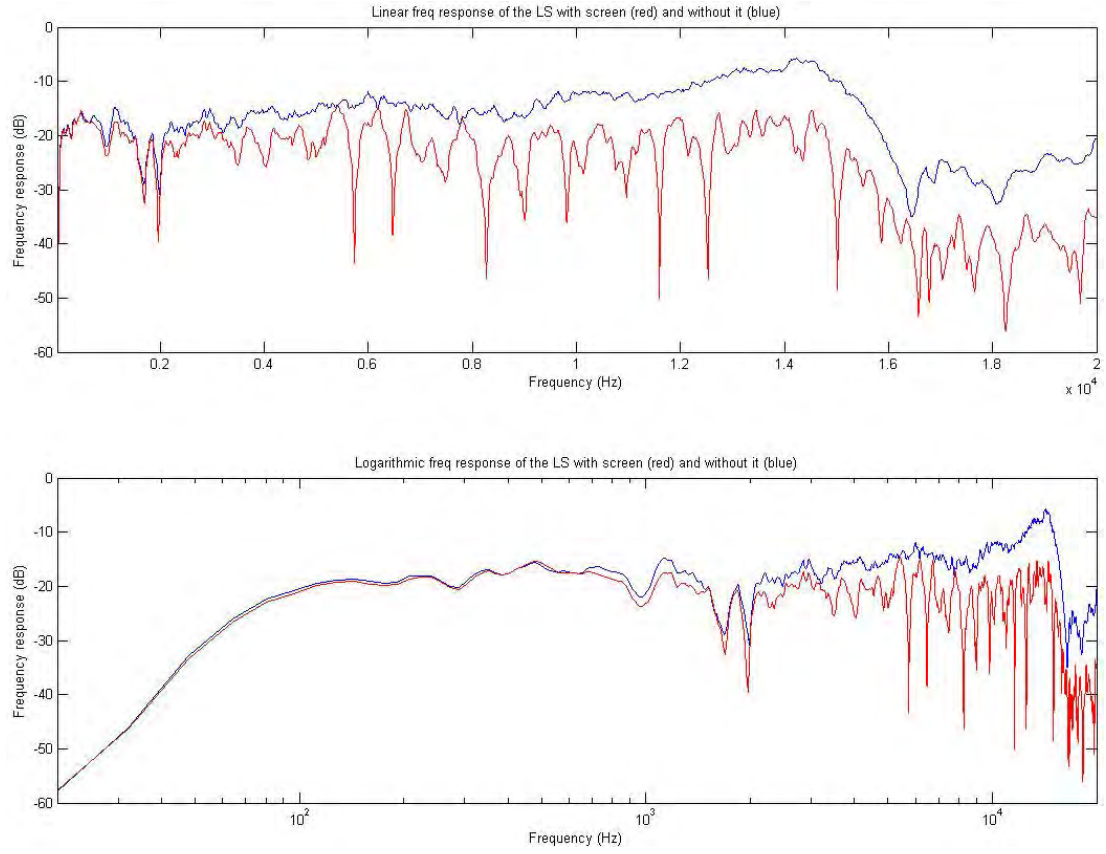

Fig. A. 58: Freq. response for Matt Plus Miniperforated with screen angled 10 degrees. Mic position 15 deg

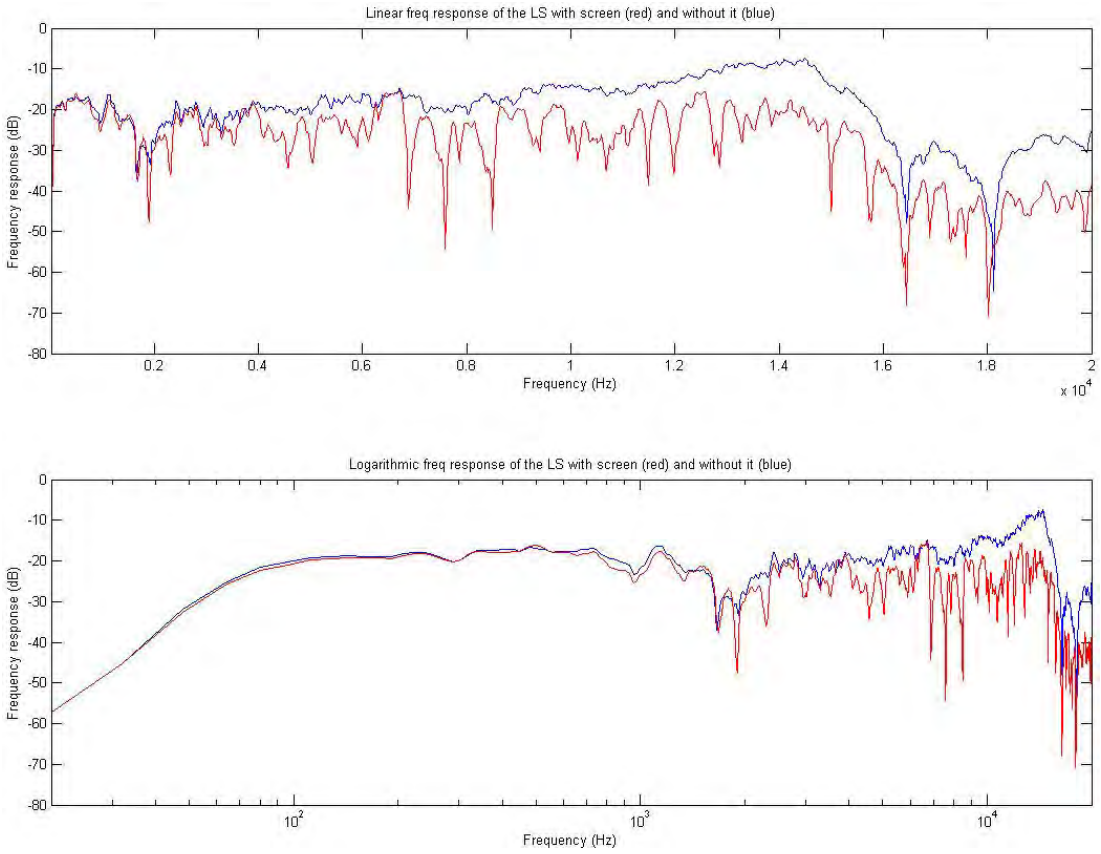

Fig. A. 59: Freq. response for Matt Plus Miniperforated with screen angled 10 degrees. Mic position 30 deg

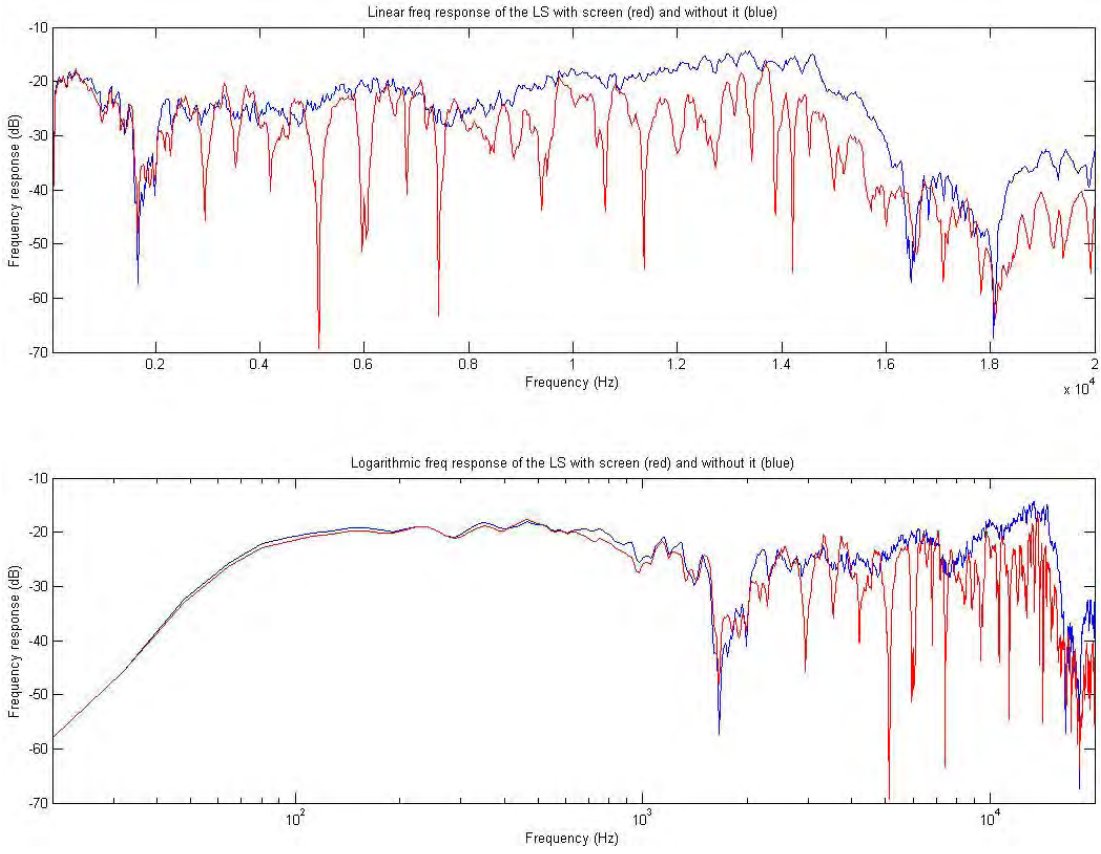

Fig. A. 60: Freq. response for Matt Plus Miniperforated with screen angled 10 degrees. Mic position 45 deg

Frequency response for Matt Plus Miniperforated with screen angled 25 deg

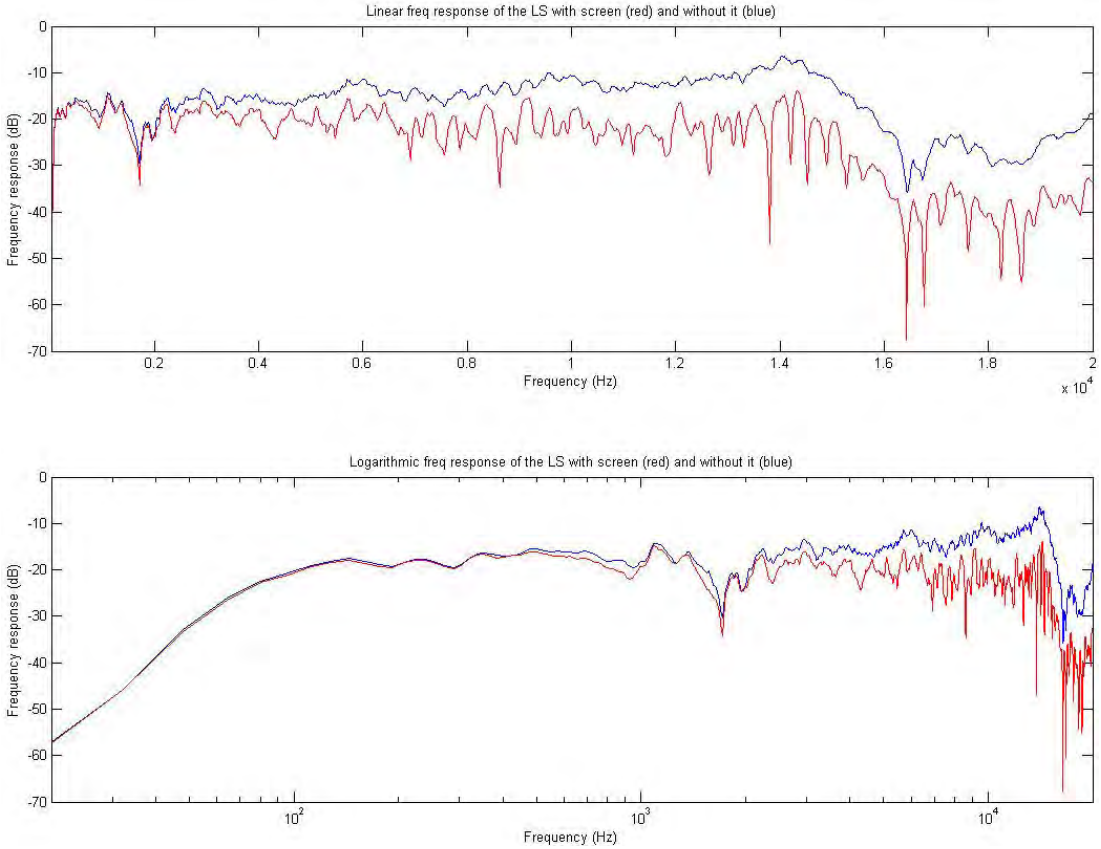

Fig. A. 61: Freq. response for Matt Plus Miniperforated with screen angled 25 degrees. Mic position 0 deg

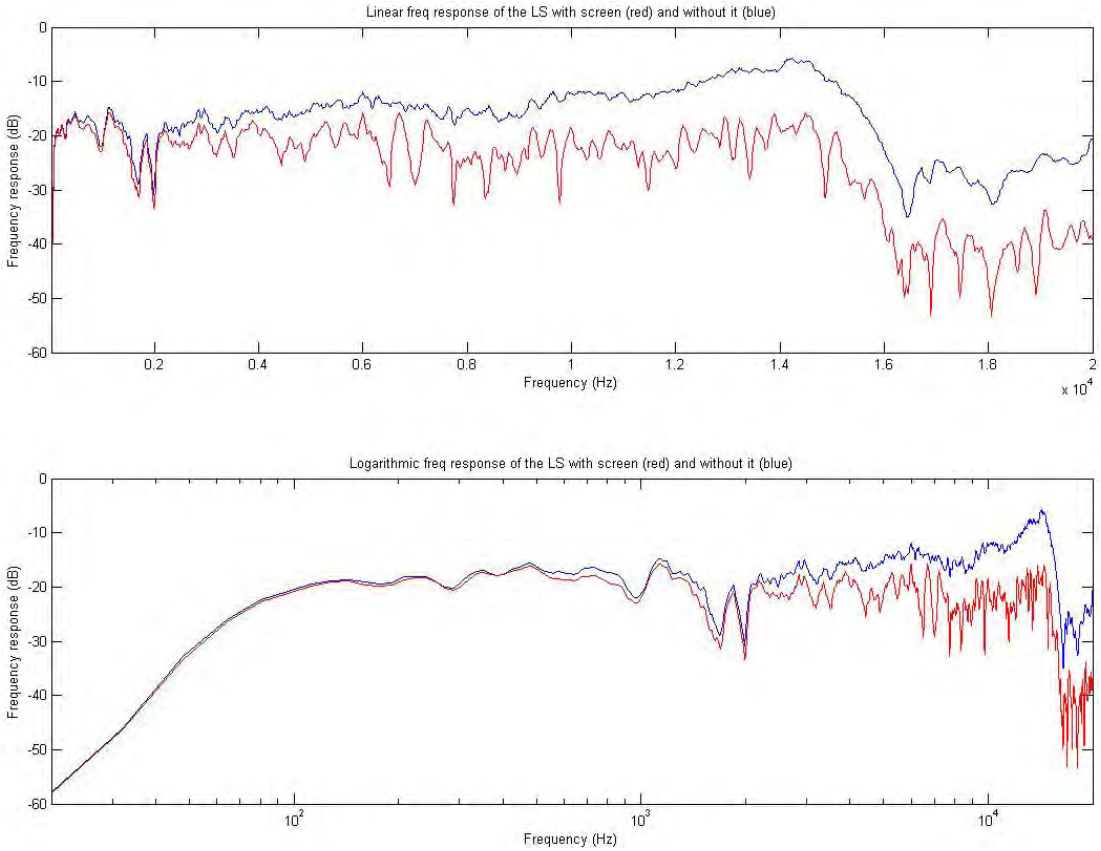

Fig. A. 62: Freq. response for Matt Plus Miniperforated with screen angled 25 degrees. Mic position 15 deg

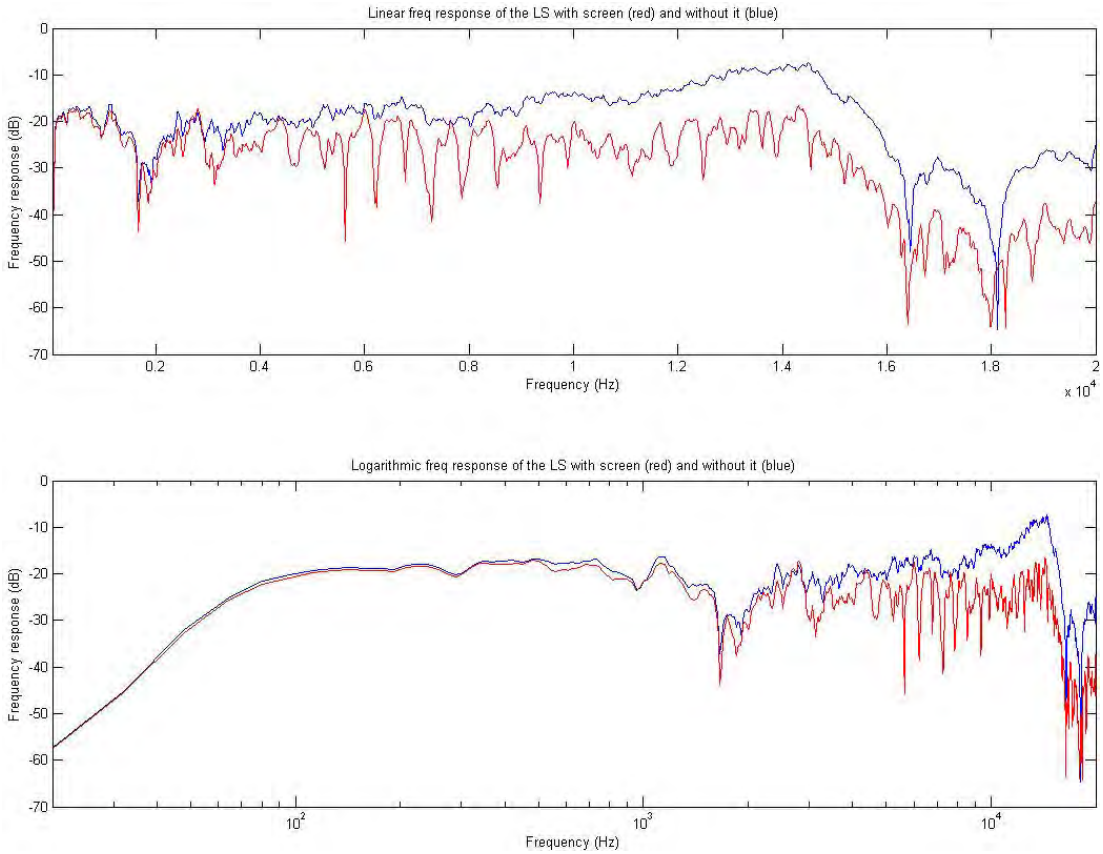

Fig. A. 63: Freq. response for Matt Plus Miniperforated with screen angled 25 degrees. Mic position 30 deg

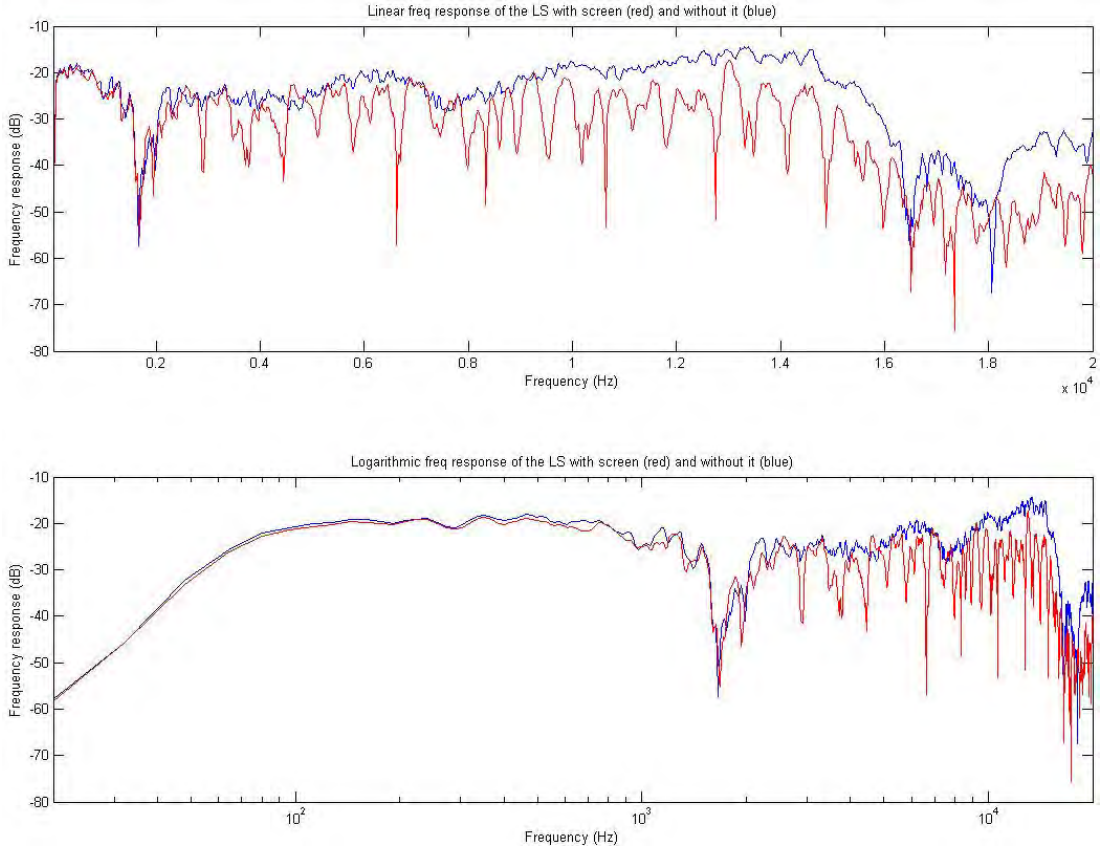

Fig. A. 64: Freq. response for Matt Plus Miniperforated with screen angled 25 degrees. Mic position 45 deg

A. 3. ClearPix 2 White 1.0

Frequency response for screen ClearPix 2 White 1.0 at a distance of 2 cm

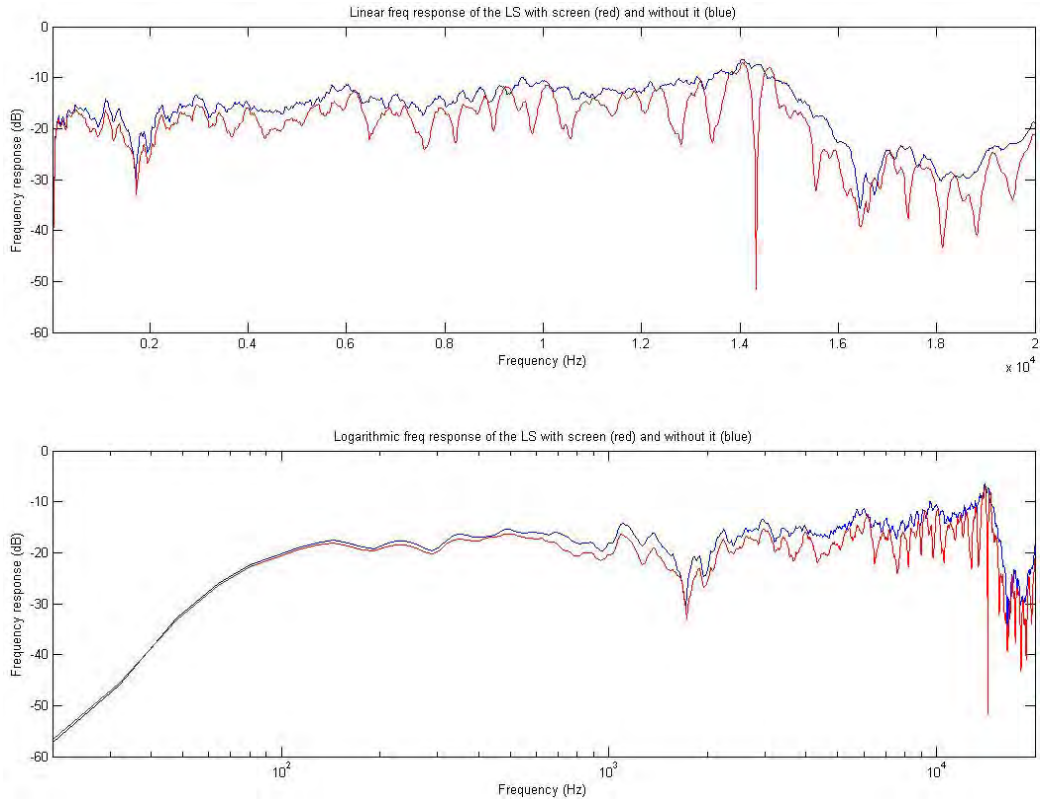

Fig. A. 65: Freq. response for screen ClearPix 2 White 1.0 at a distance of 2 cm. 0 degrees

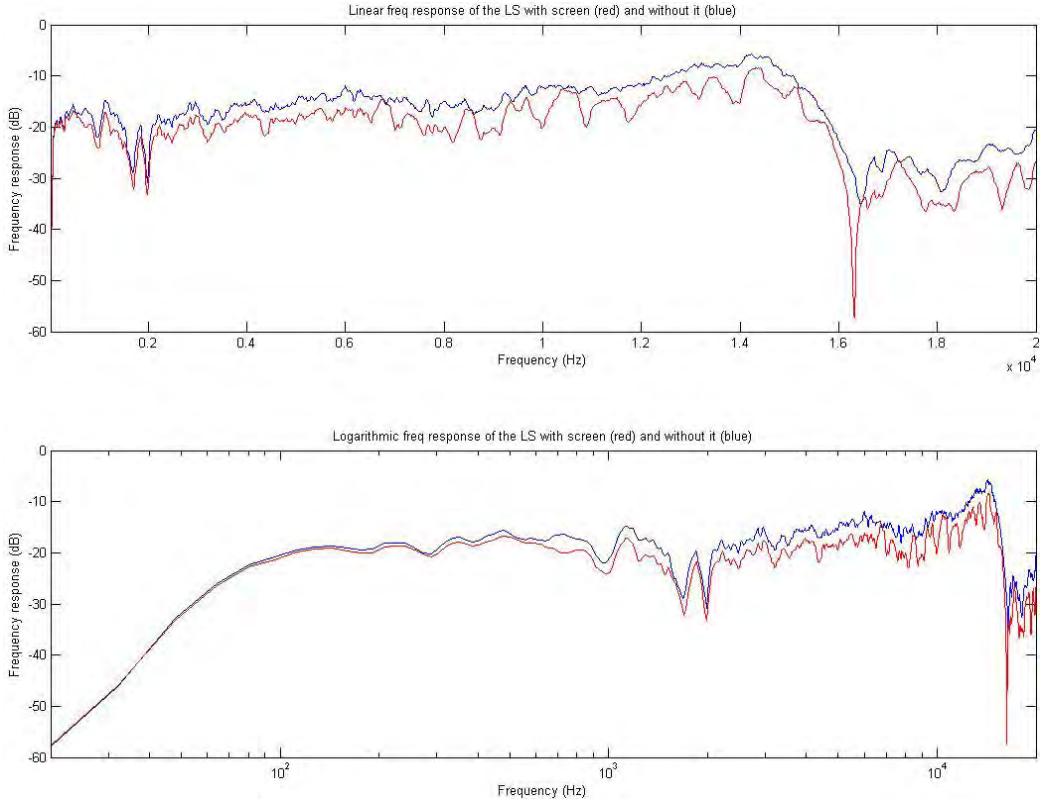

Fig. A. 66: Freq. response for screen ClearPix 2 White 1.0 at a distance of 2 cm. 15 degrees

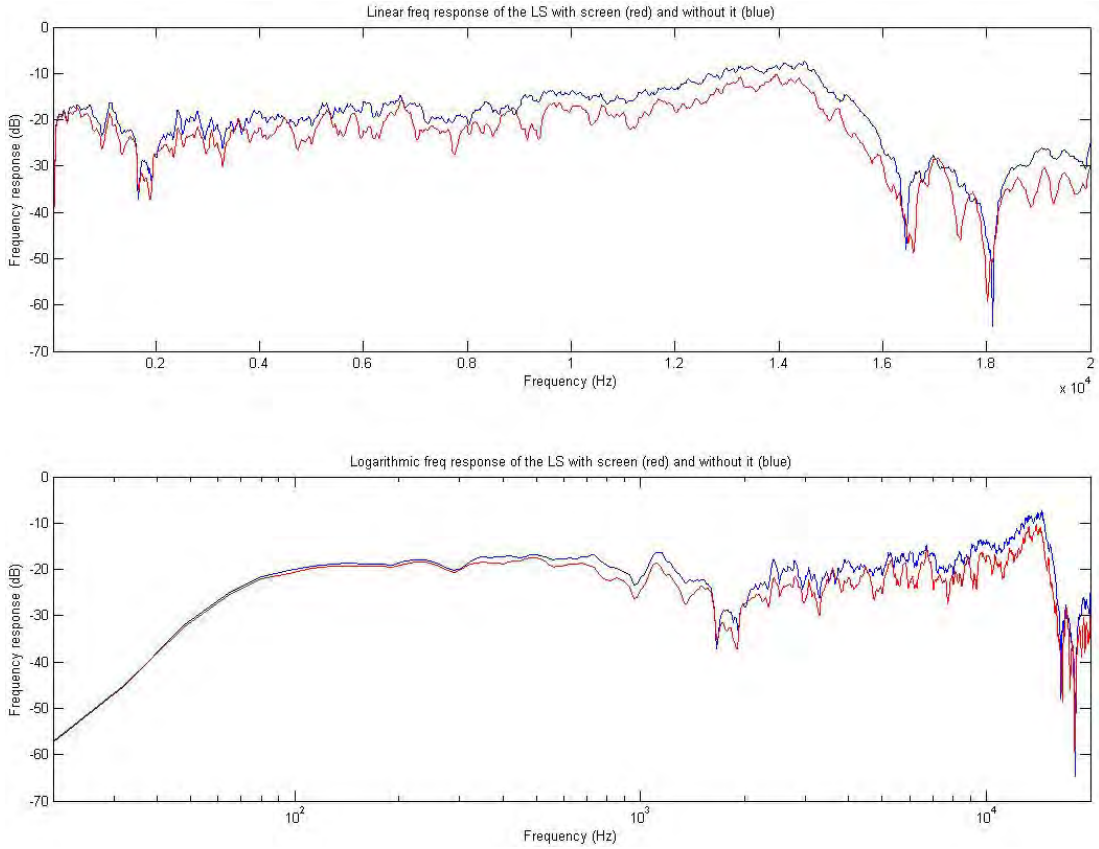

Fig. A. 67: Freq. response for screen ClearPix 2 White 1.0 at a distance of 2 cm. 30 degrees

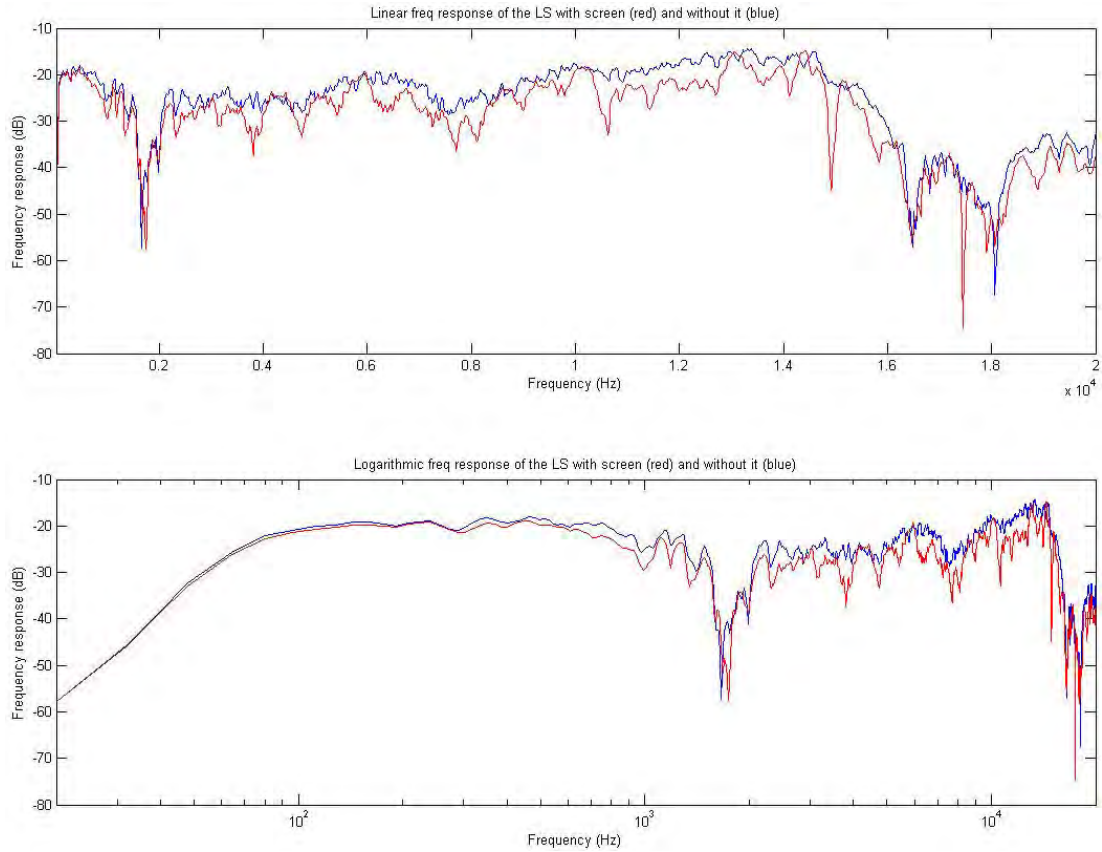

Fig. A. 68: Freq. response for screen ClearPix 2 White 1.0 at a distance of 2 cm. 45 degrees

Frequency response for screen ClearPix 2 White 1.0 at a distance of 7 cm

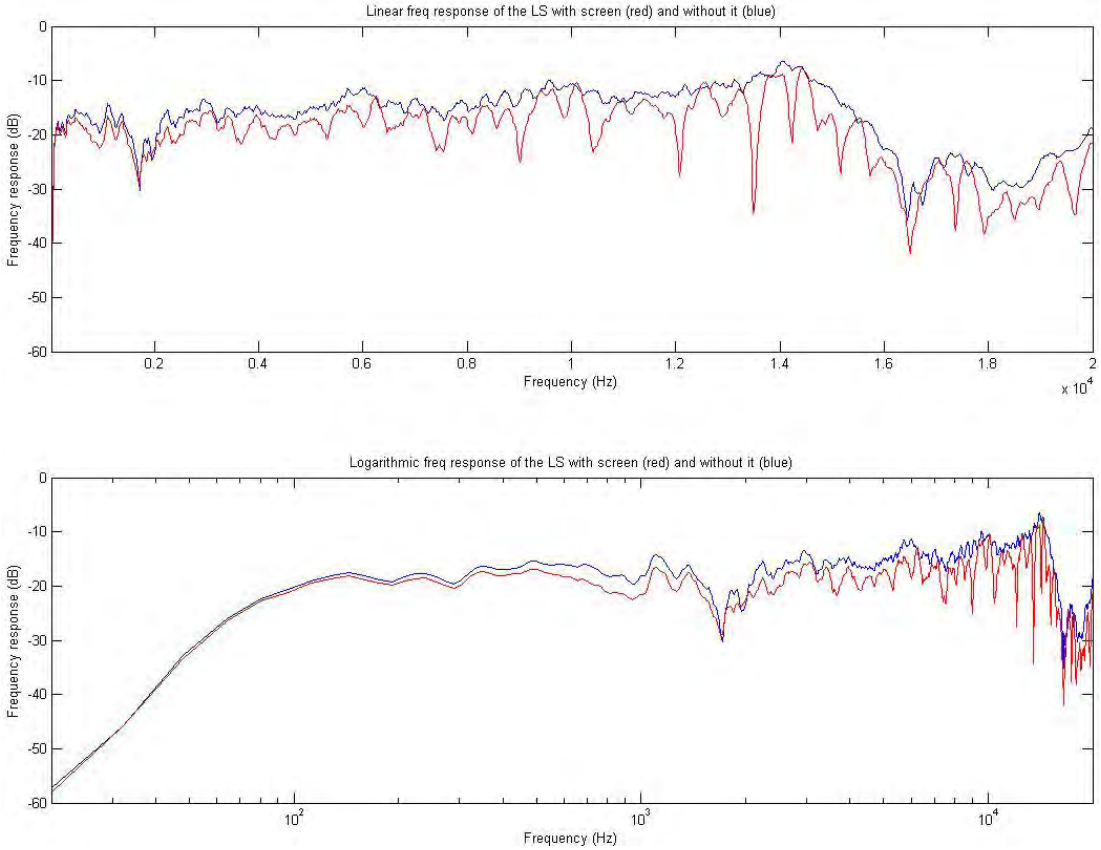

Fig. A. 69: Freq. response for screen ClearPix 2 White 1.0 at a distance of 7 cm. 0 degrees

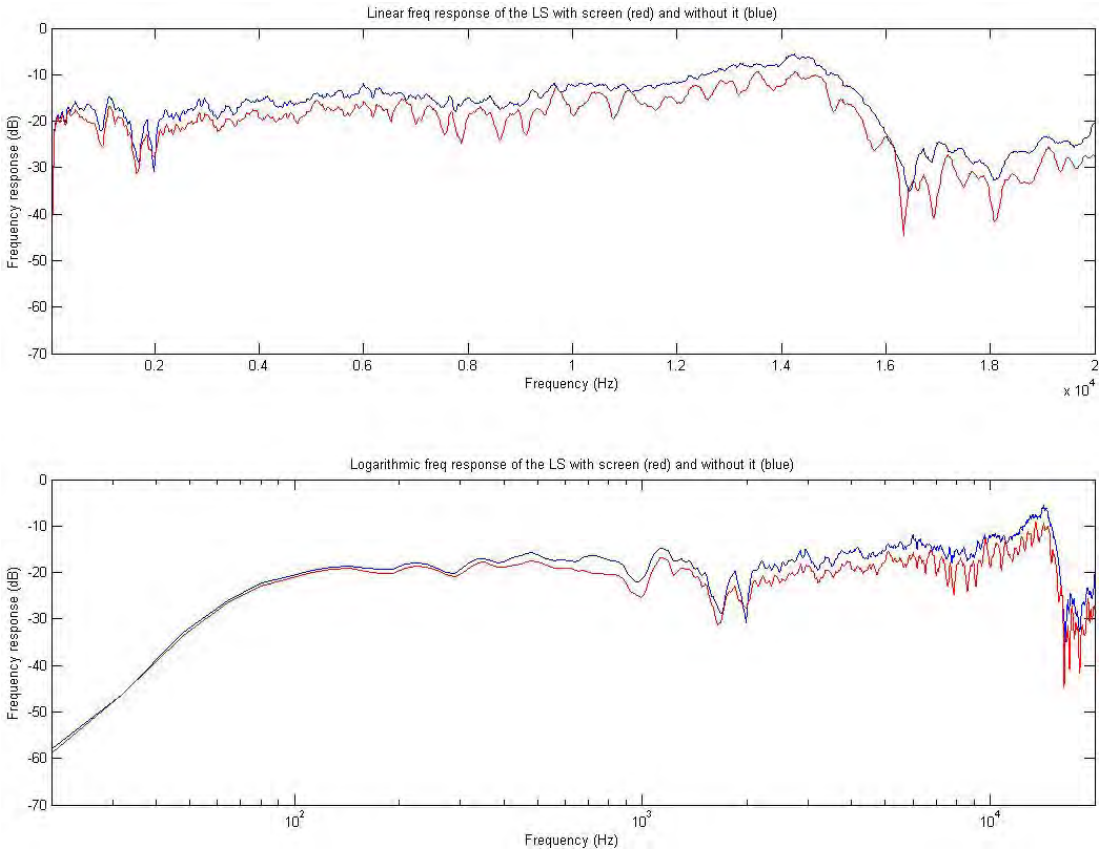

Fig. A. 70: Freq. response for screen ClearPix 2 White 1.0 at a distance of 7 cm. 15 degrees

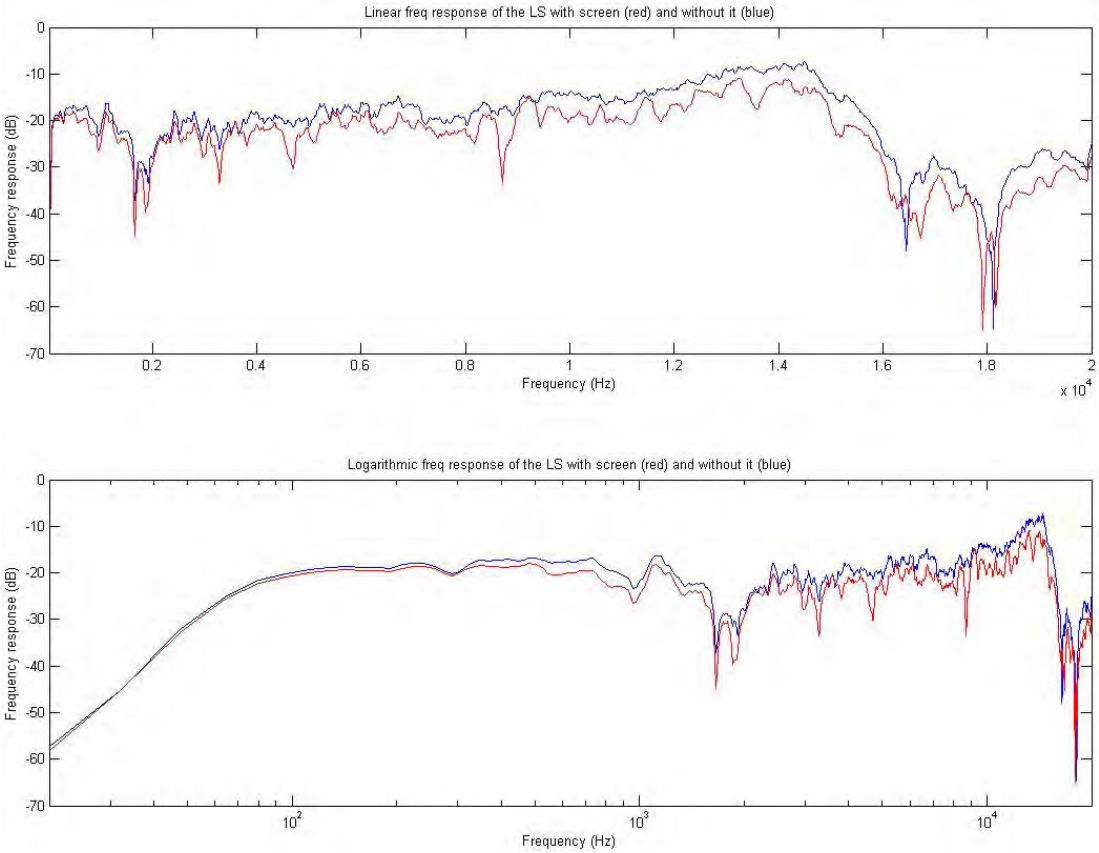

Fig. A. 71: Freq. response for screen ClearPix 2 White 1.0 at a distance of 7 cm. 30 degrees

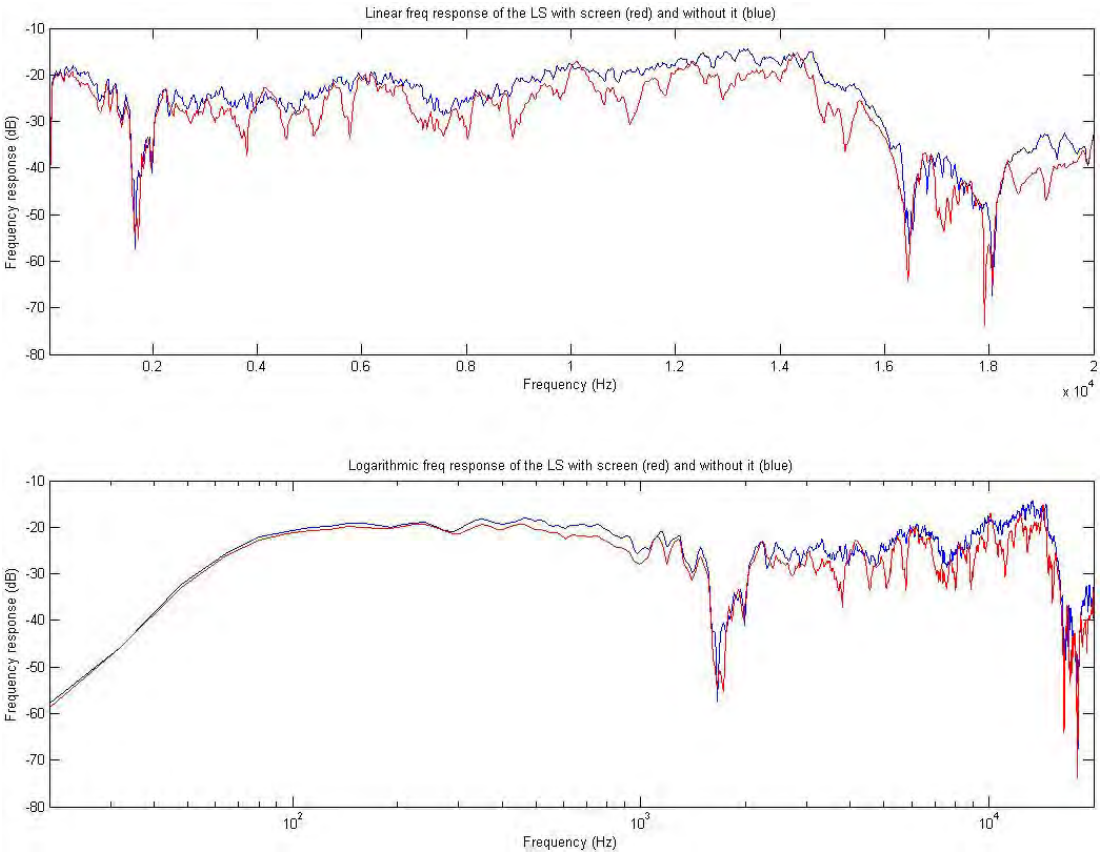

Fig. A. 72: Freq. response for screen ClearPix 2 White 1.0 at a distance of 7 cm. 45 degrees

Frequency response for screen ClearPix 2 White 1.0 at a distance of 15 cm

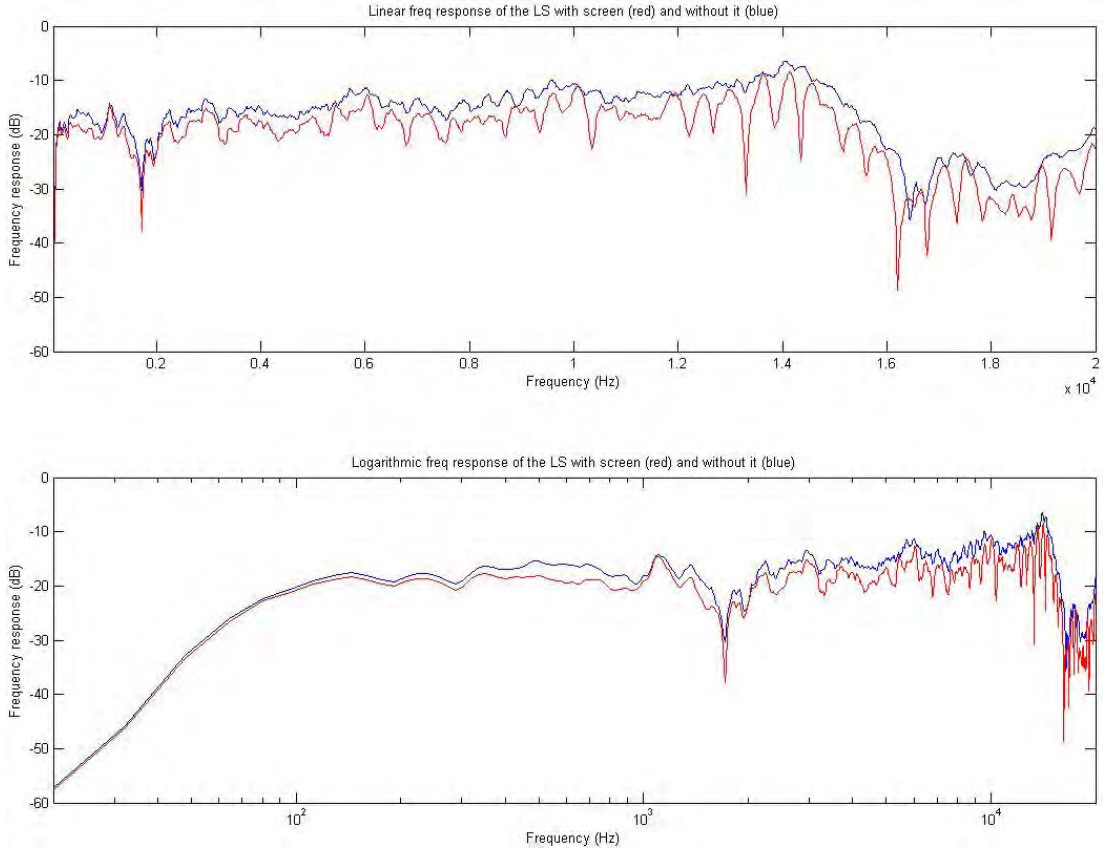

Fig. A. 73: Freq. response for screen ClearPix 2 White 1.0 at a distance of 15 cm. 0 degrees

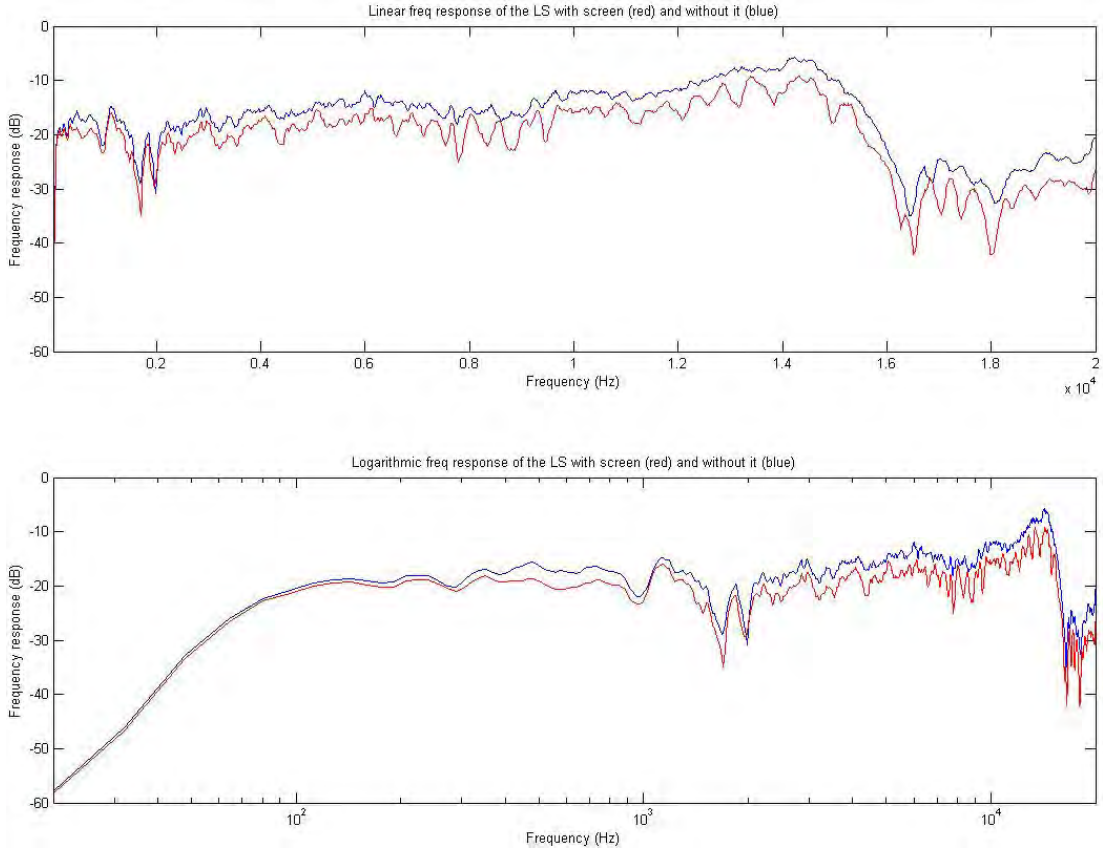

Fig. A. 74: Freq. response for screen ClearPix 2 White 1.0 at a distance of 15 cm. 15 degrees

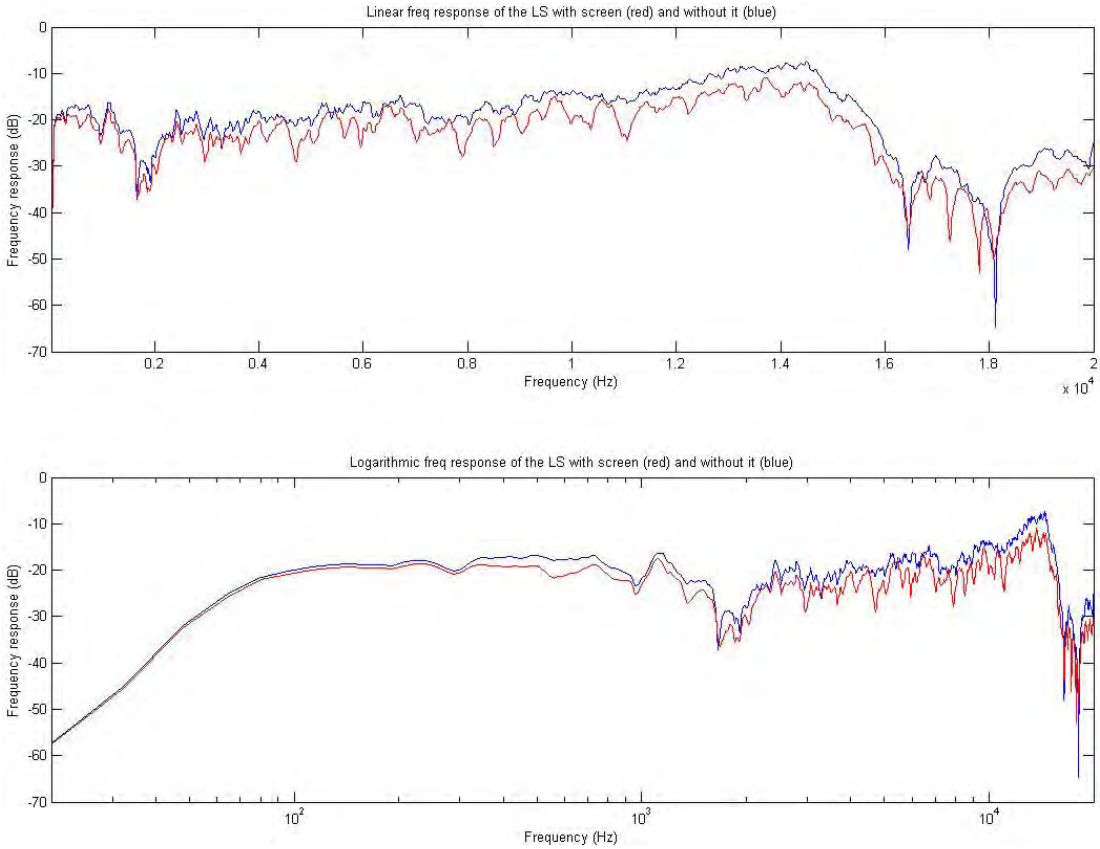

Fig. A. 75: Freq. response for screen ClearPix 2 White 1.0 at a distance of 15 cm. 30 degrees

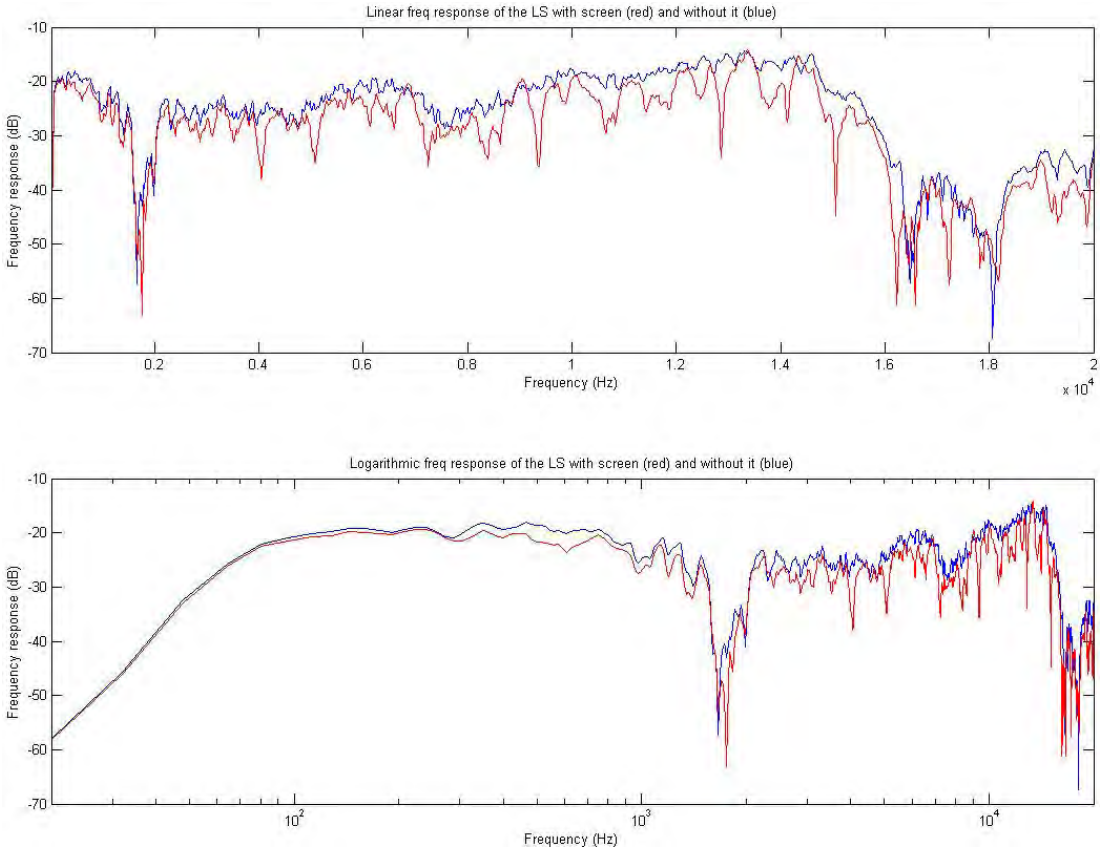

Fig. A. 76: Freq. response for screen ClearPix 2 White 1.0 at a distance of 15 cm. 45 degrees

Frequency response for screen ClearPix 2 White 1.0 at a distance of 30 cm

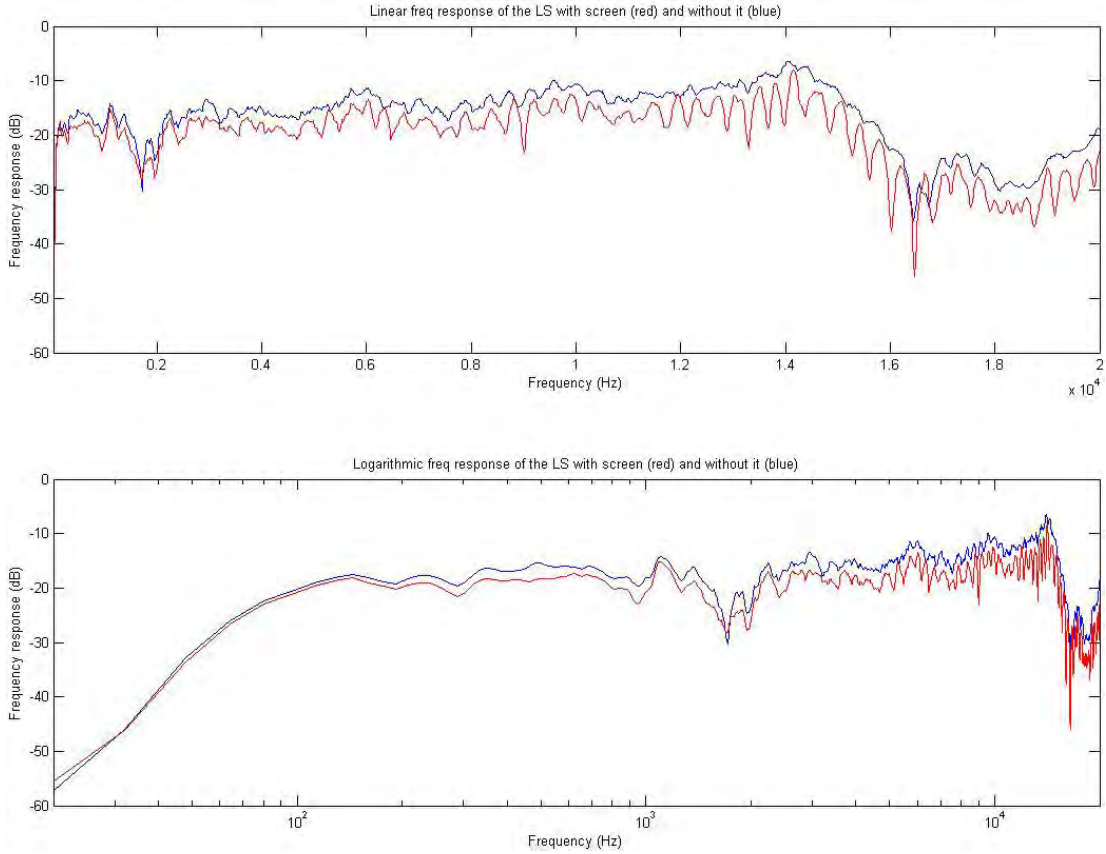

Fig. A. 77: Freq. response for screen ClearPix 2 White 1.0 at a distance of 30 cm. 0 degrees

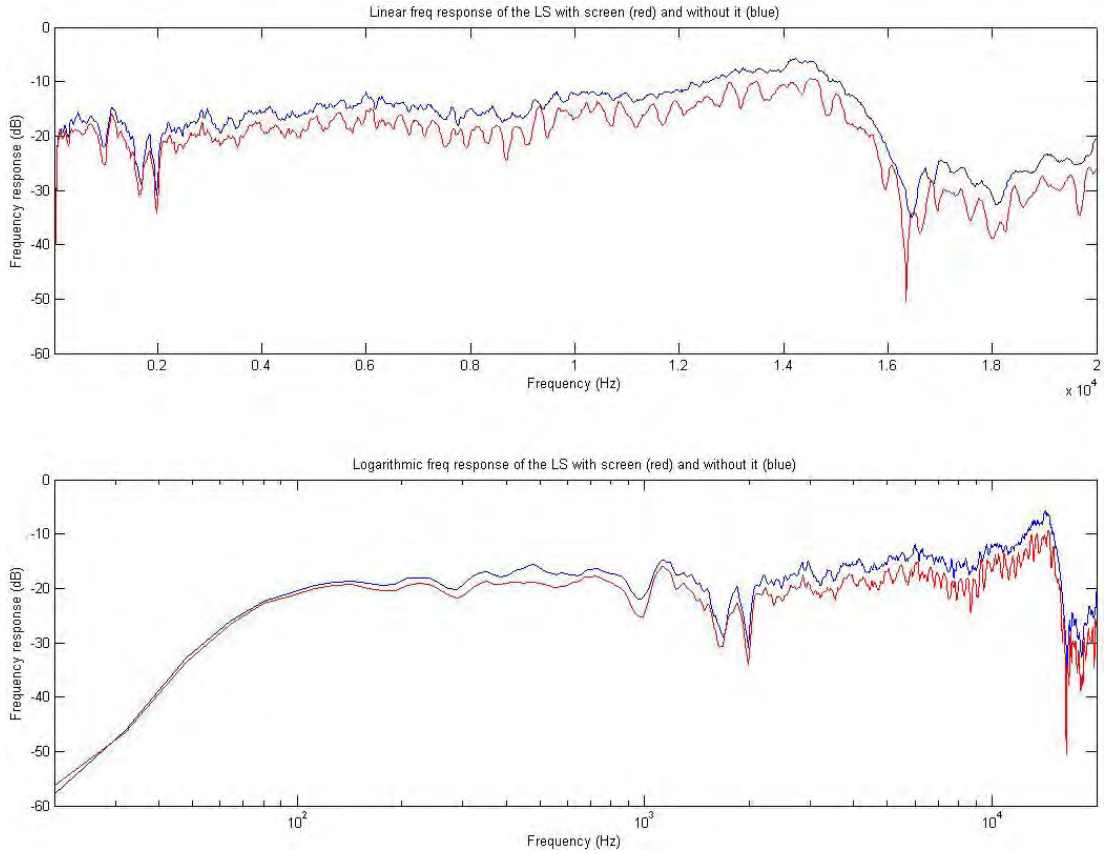

Fig. A. 78: Freq. response for screen ClearPix 2 White 1.0 at a distance of 30 cm. 15 degrees

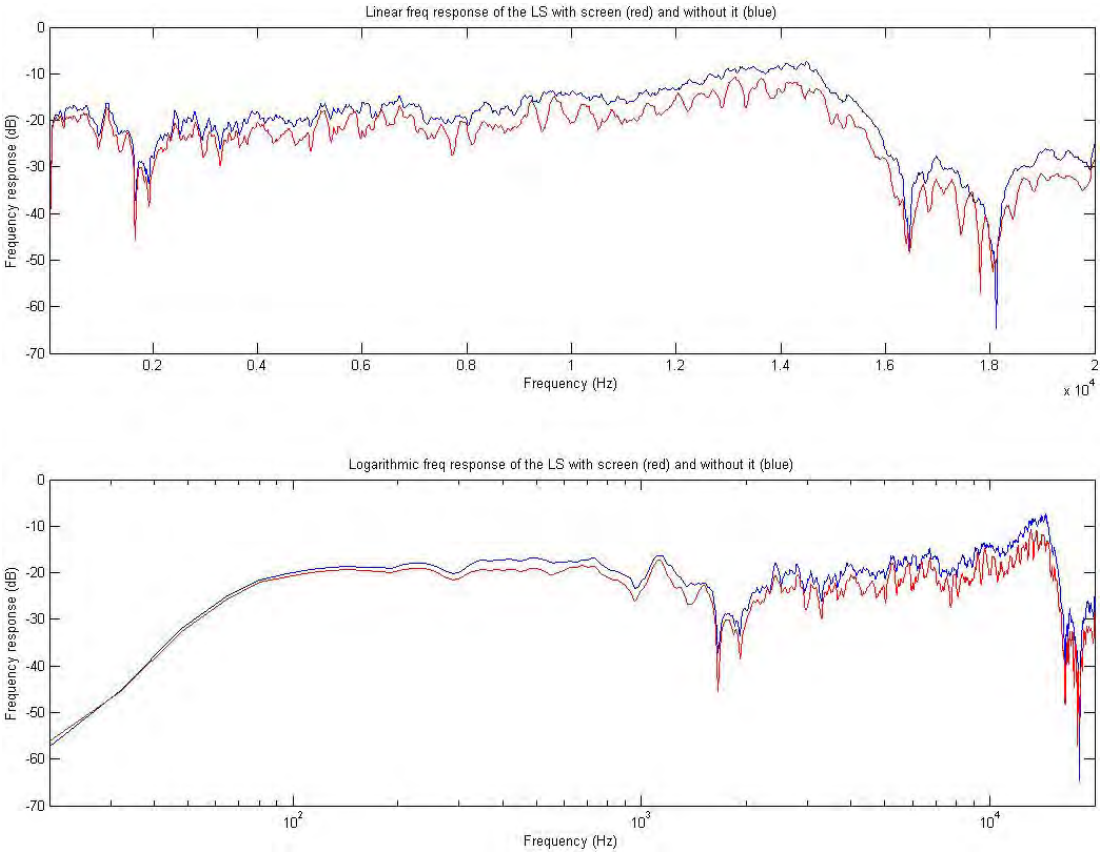

Fig. A. 79: Freq. response for screen ClearPix 2 White 1.0 at a distance of 30 cm. 30 degrees

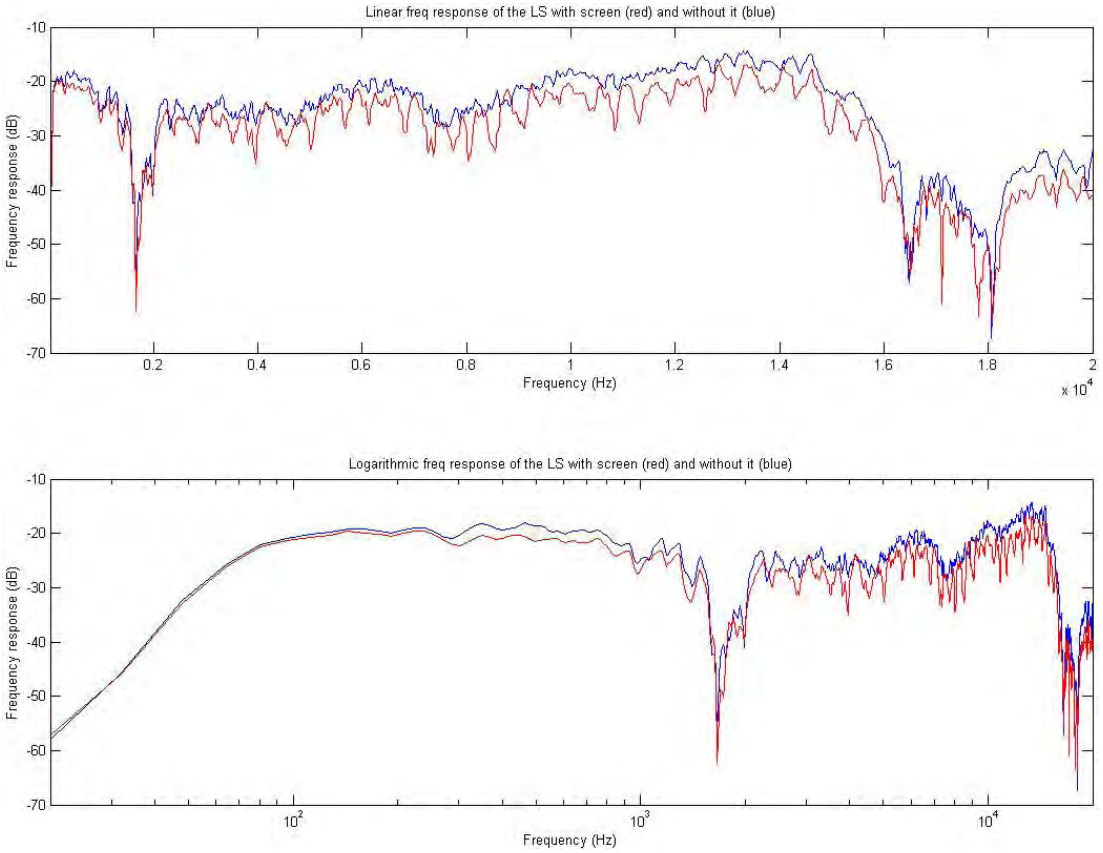

Fig. A. 80: Freq. response for screen ClearPix 2 White 1.0 at a distance of 30 cm. 45 degrees

Frequency response for screen ClearPix 2 White 1.0 at a distance of 45 cm

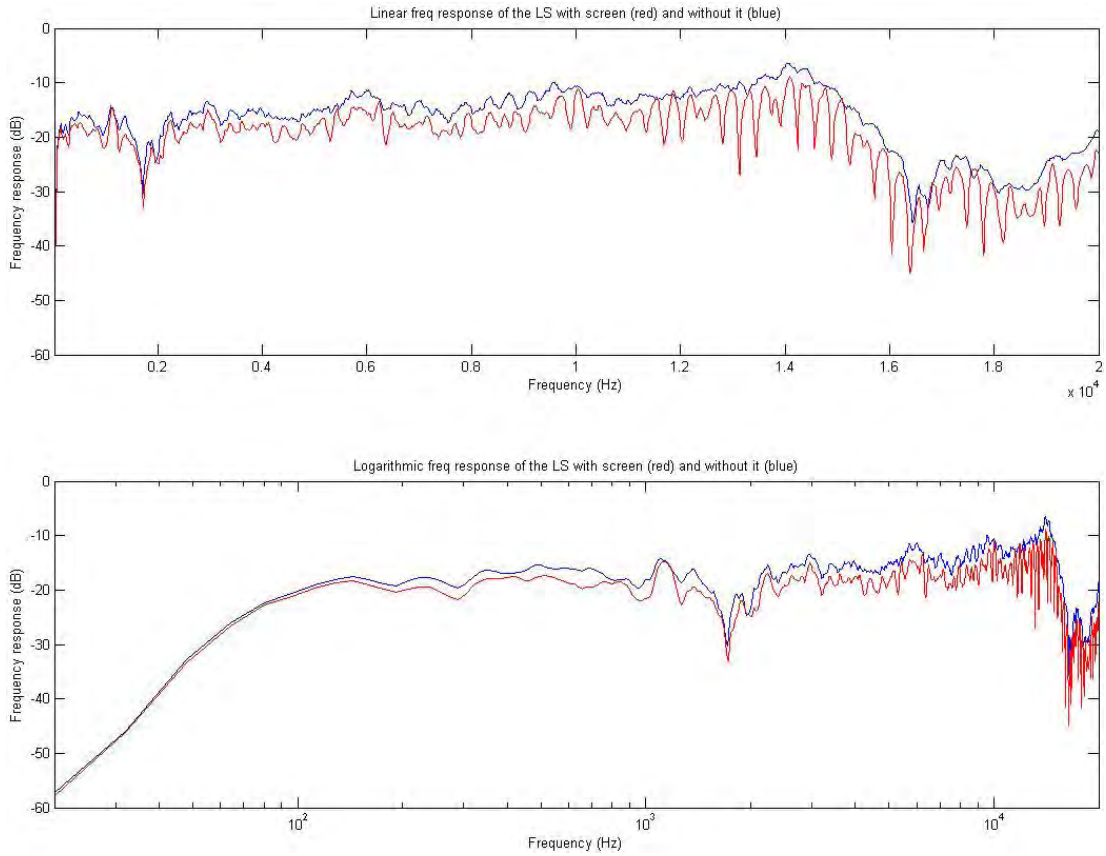

Fig. A. 81: Freq. response for screen ClearPix 2 White 1.0 at a distance of 45 cm. 0 degrees

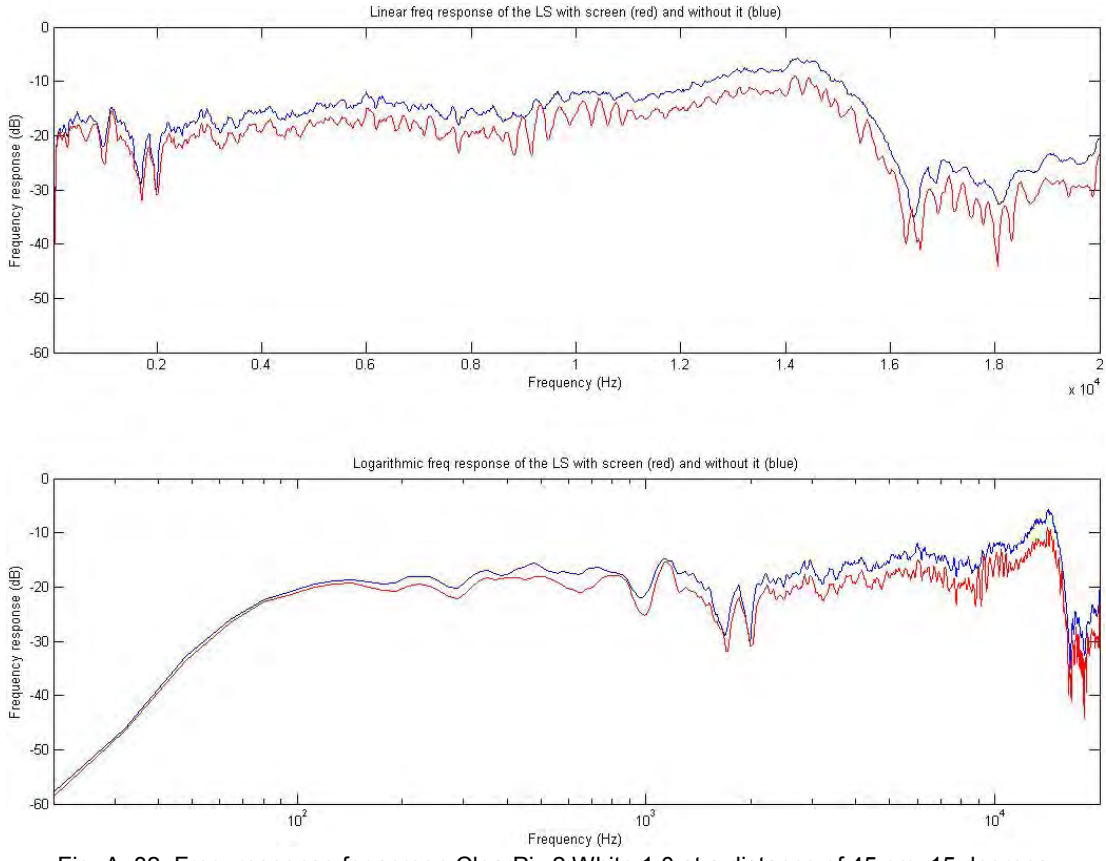

Fig. A. 82: Freq. response for screen ClearPix 2 White 1.0 at a distance of 45 cm. 15 degrees

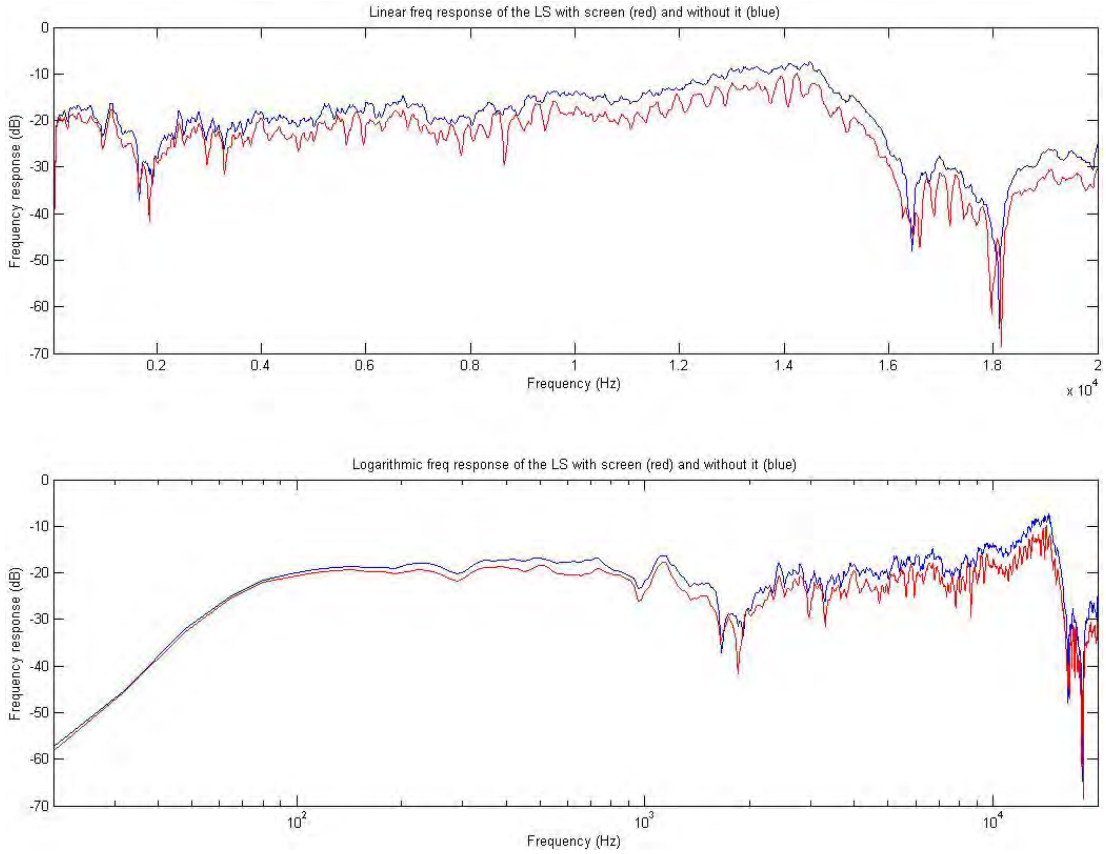

Fig. A. 83: Freq. response for screen ClearPix 2 White 1.0 at a distance of 45 cm. 30 degrees

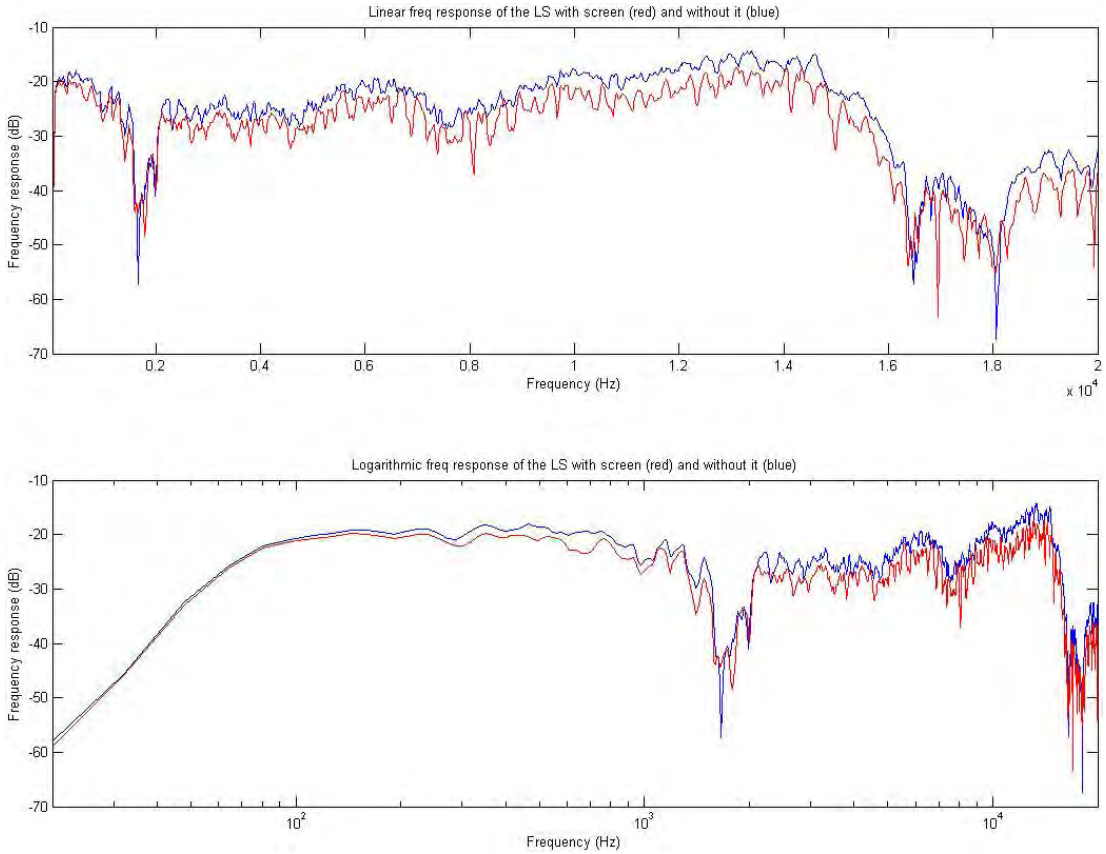

Fig. A. 84: Freq. response for screen ClearPix 2 White 1.0 at a distance of 45 cm. 45 degrees

Frequency response for screen ClearPix 2 White 1.0 at a distance of 60 cm

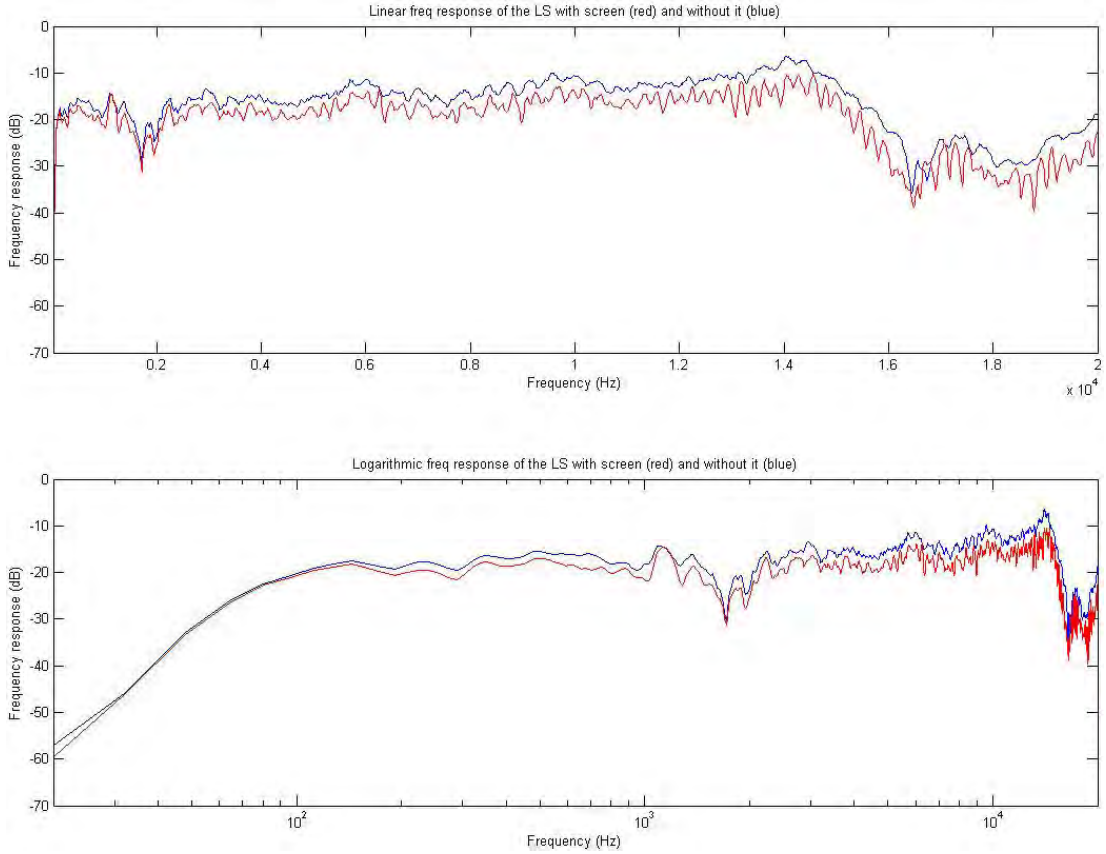

Fig. A. 85: Freq. response for screen ClearPix 2 White 1.0 at a distance of 60 cm. 0 degrees

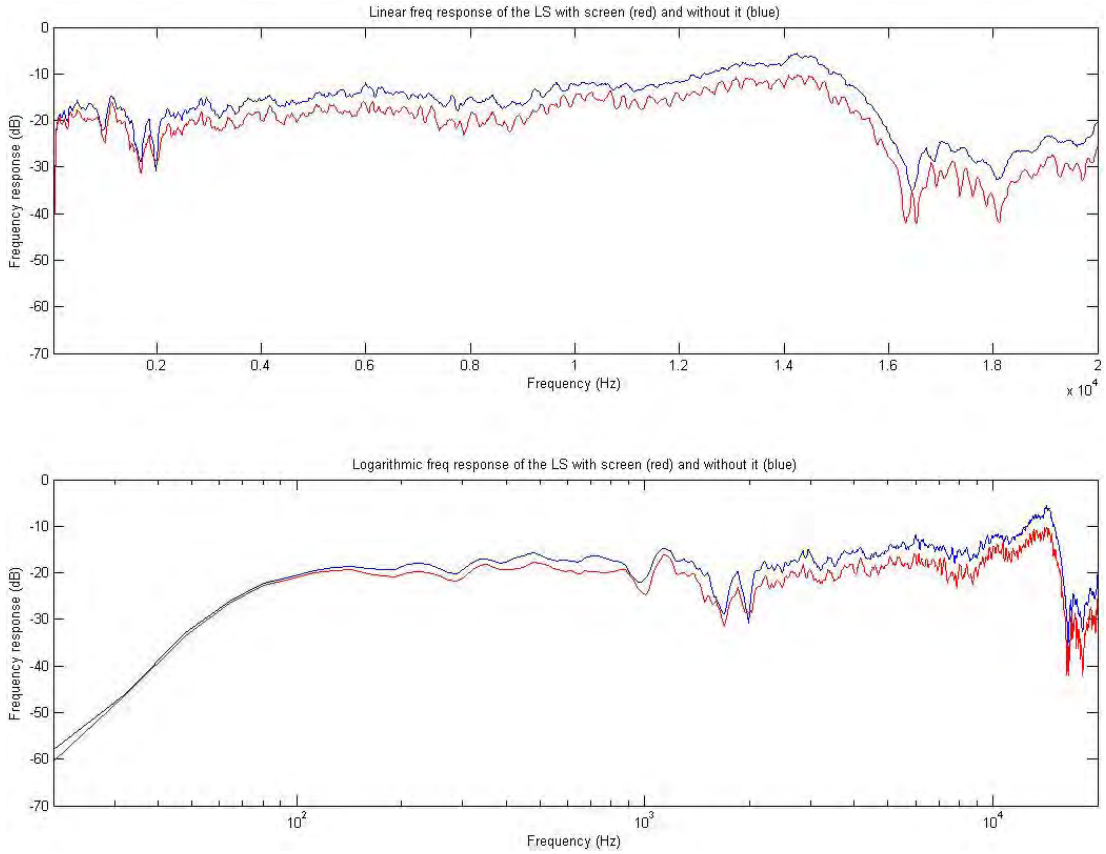

Fig. A. 86: Freq. response for screen ClearPix 2 White 1.0 at a distance of 60 cm. 15 degrees

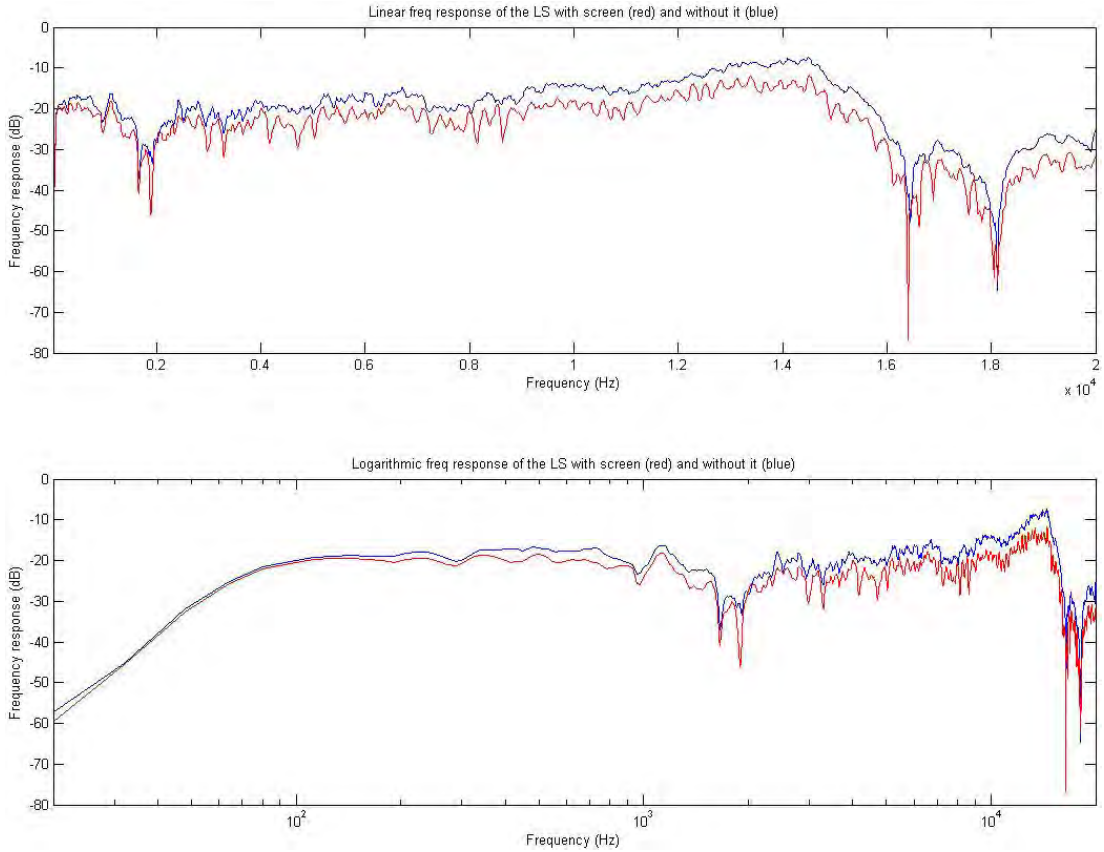

Fig. A. 87: Freq. response for screen ClearPix 2 White 1.0 at a distance of 60 cm. 30 degrees

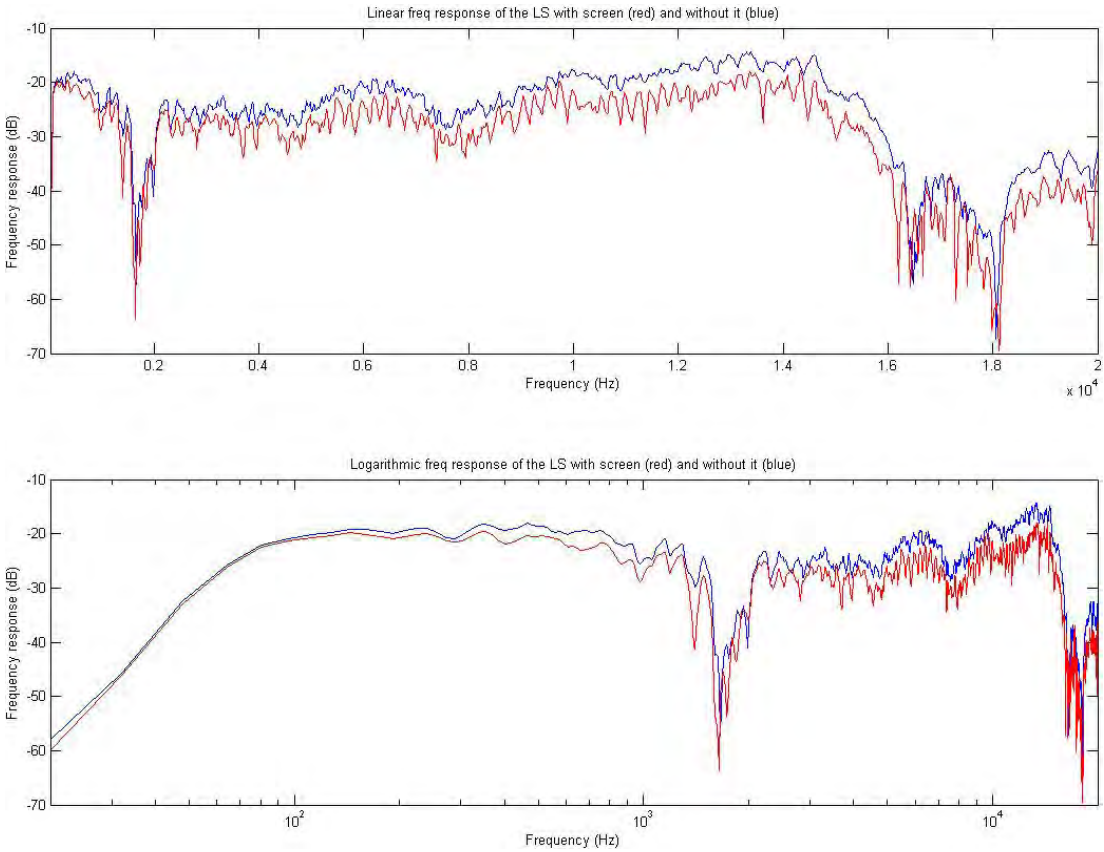

Fig. A. 88: Freq. response for screen ClearPix 2 White 1.0 at a distance of 60 cm. 45 degrees

Frequency response for ClearPix 2 White 1.0 with screen angled 10 deg.

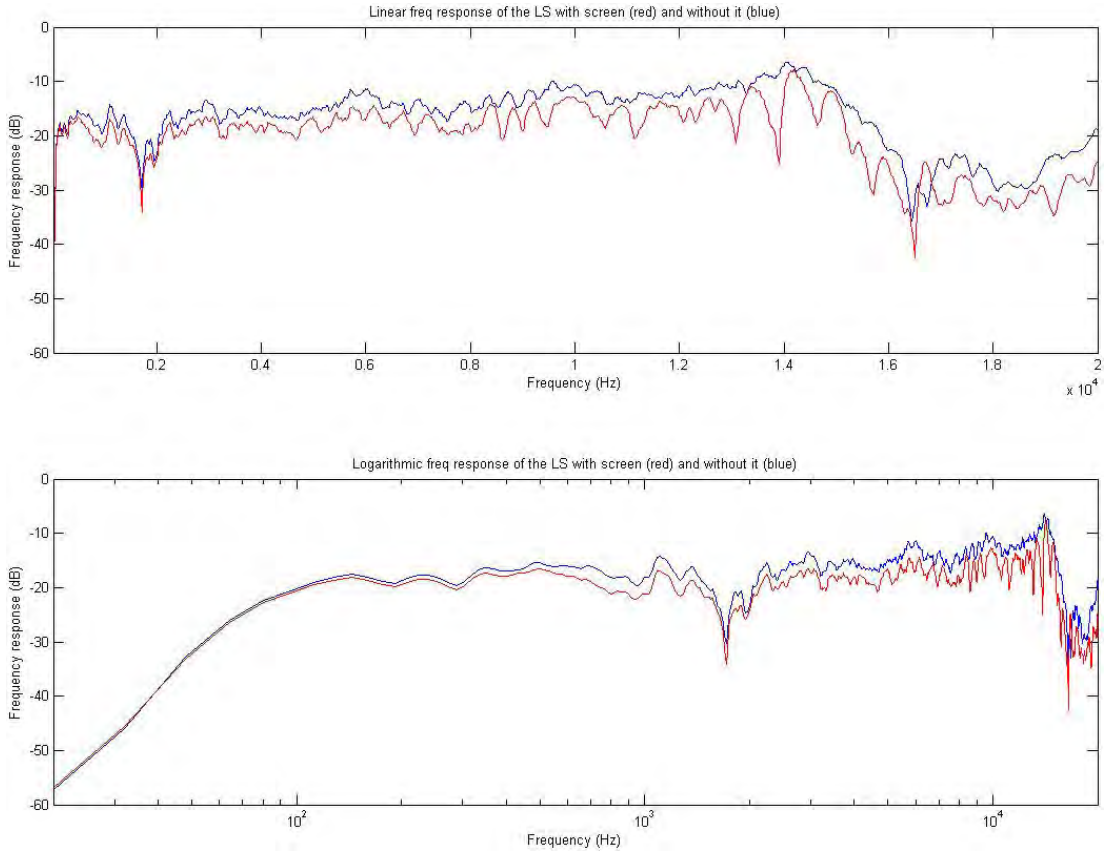

Fig. A. 89: Freq. response for ClearPix 2 White 1.0 with screen angled 10 degrees. Mic position 0 deg

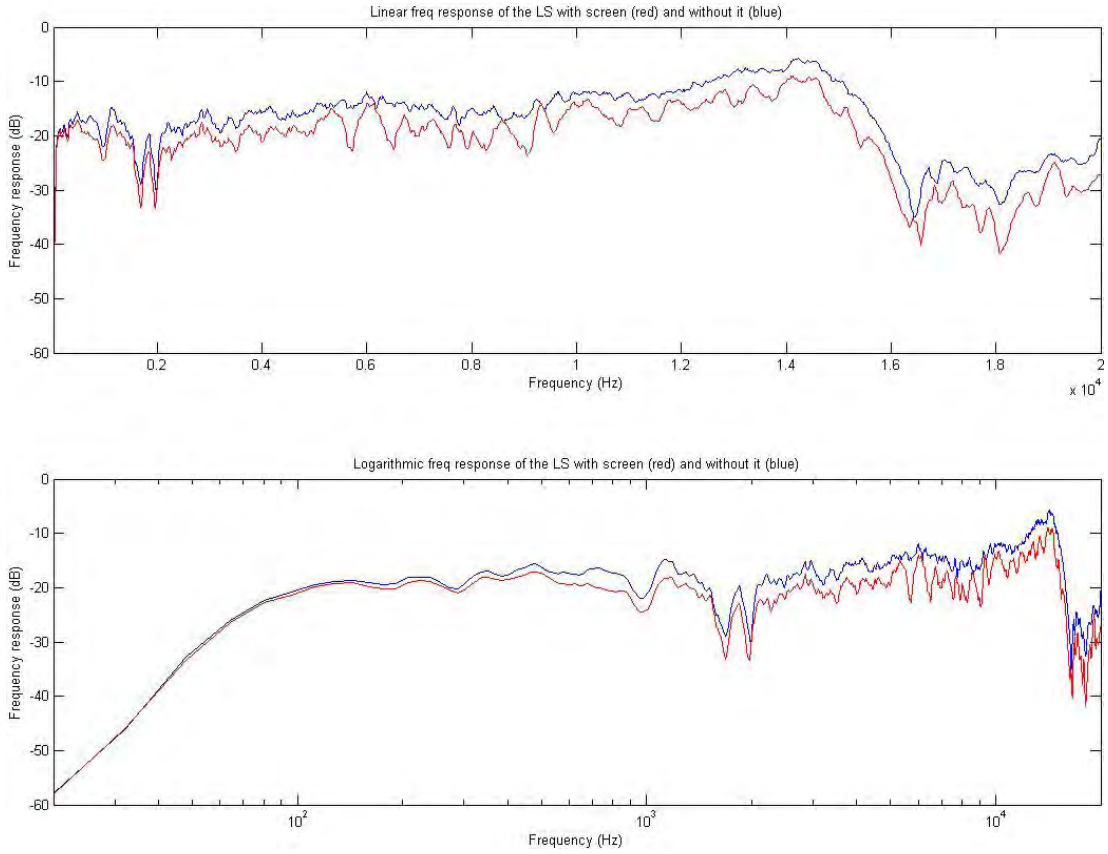

Fig. A. 90: Freq. response for ClearPix 2 White 1.0 with screen angled 10 degrees. Mic position 15 deg

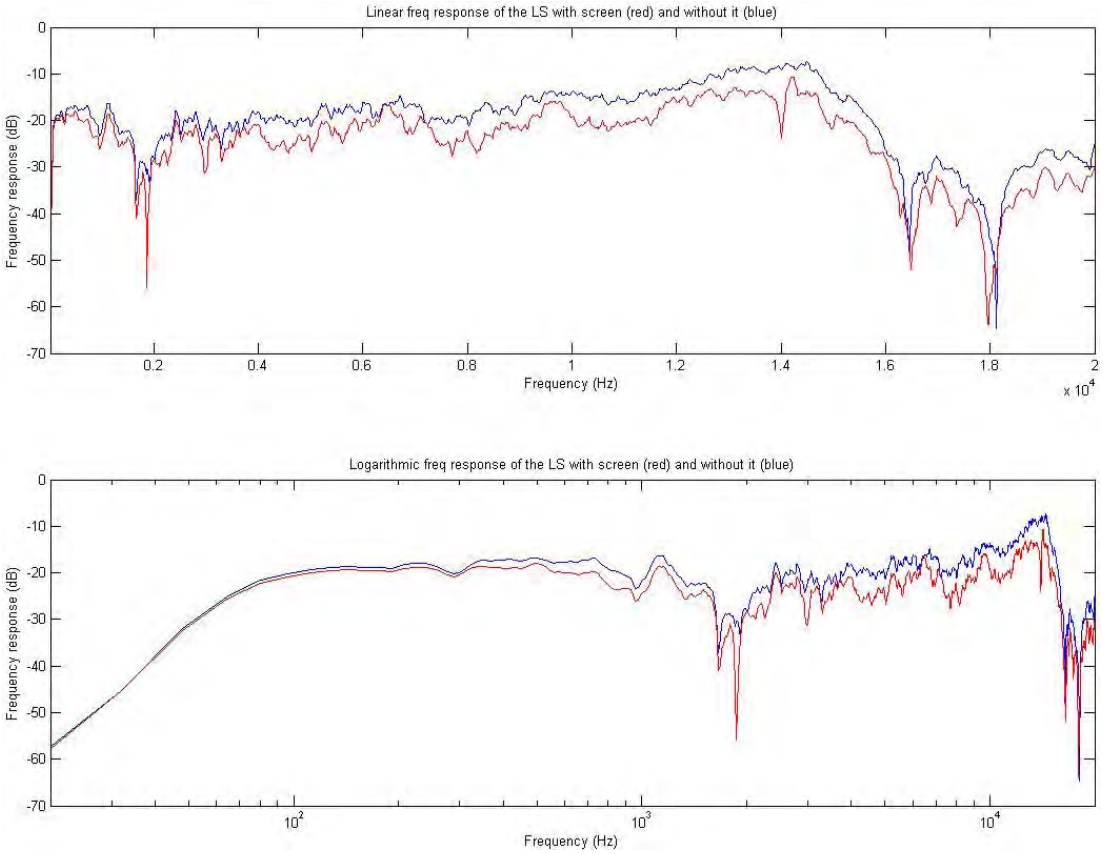

Fig. A. 91: Freq. response for ClearPix 2 White 1.0 with screen angled 10 degrees. Mic position 30 deg

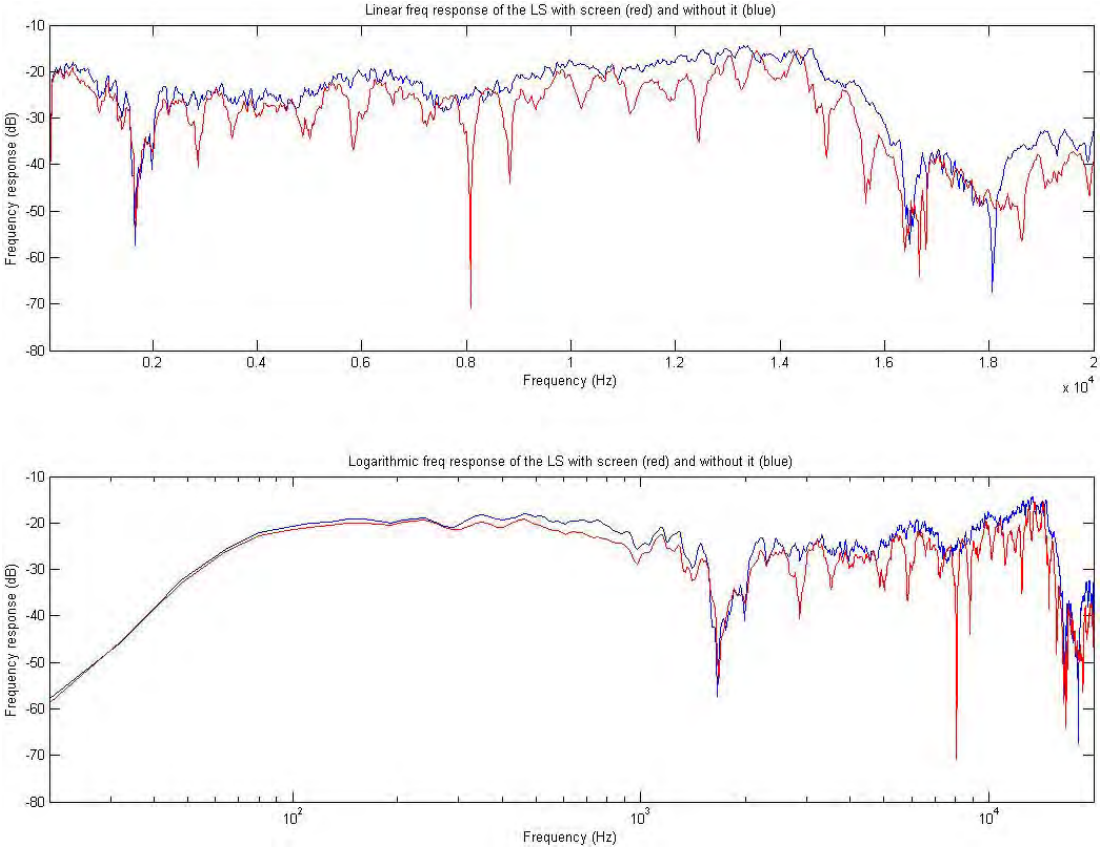

Fig. A. 92: Freq. response for ClearPix 2 White 1.0 with screen angled 10 degrees. Mic position 45 deg

Frequency response for ClearPix 2 White 1.0 with screen angled 25 deg

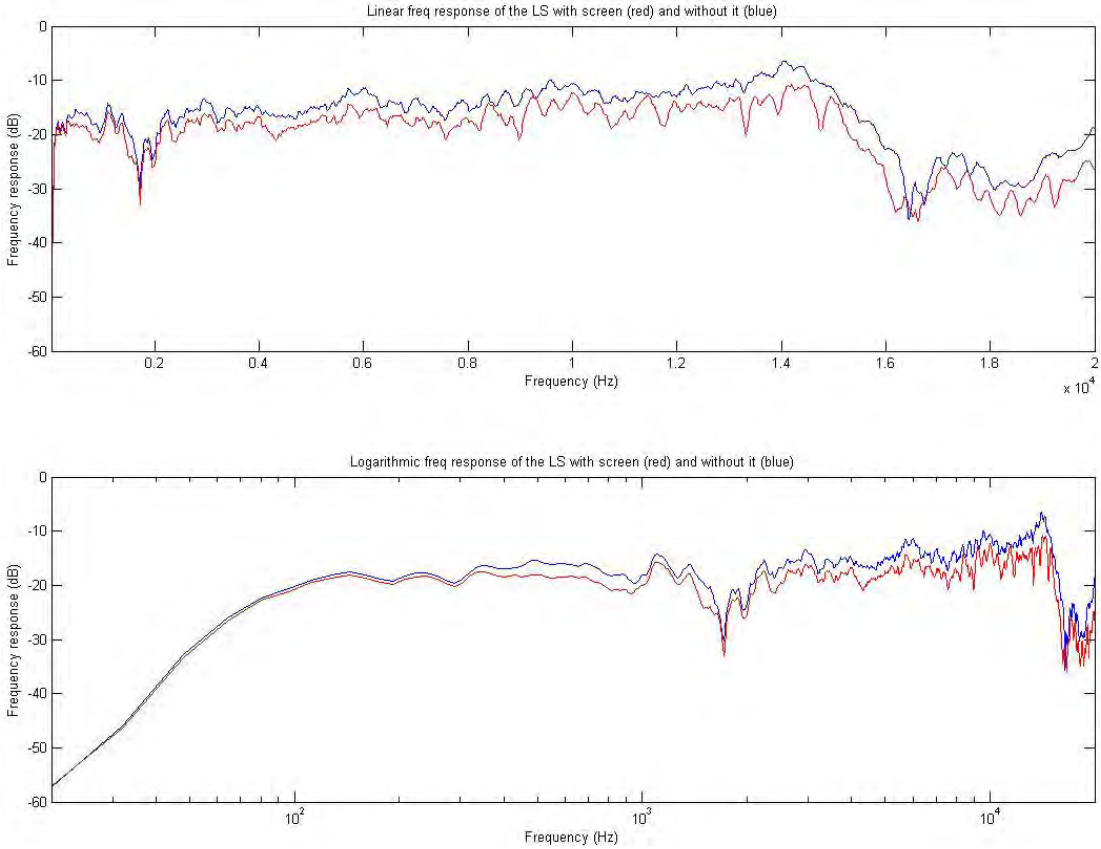

Fig. A. 93: Freq. response for ClearPix 2 White 1.0 with screen angled 25 degrees. Mic position 0 deg

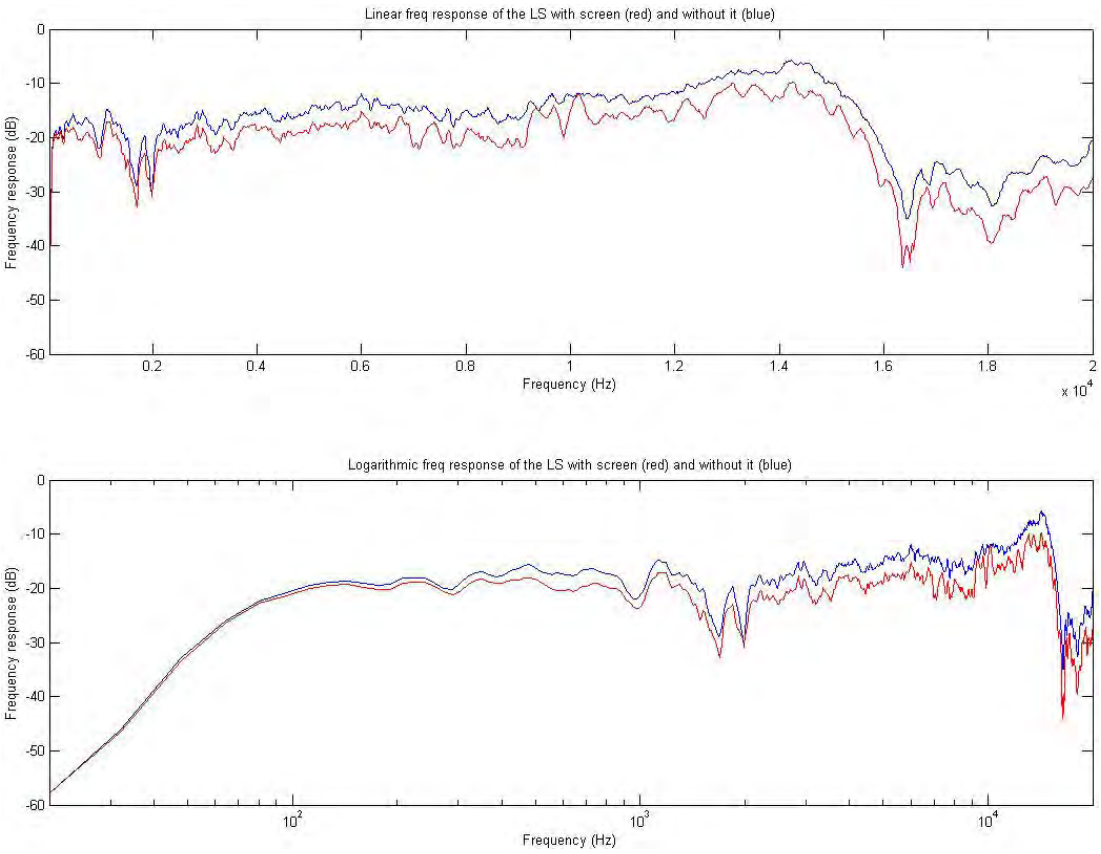

Fig. A. 94: Freq. response for ClearPix 2 White 1.0 screen angled 25 degrees. Mic position 15 deg

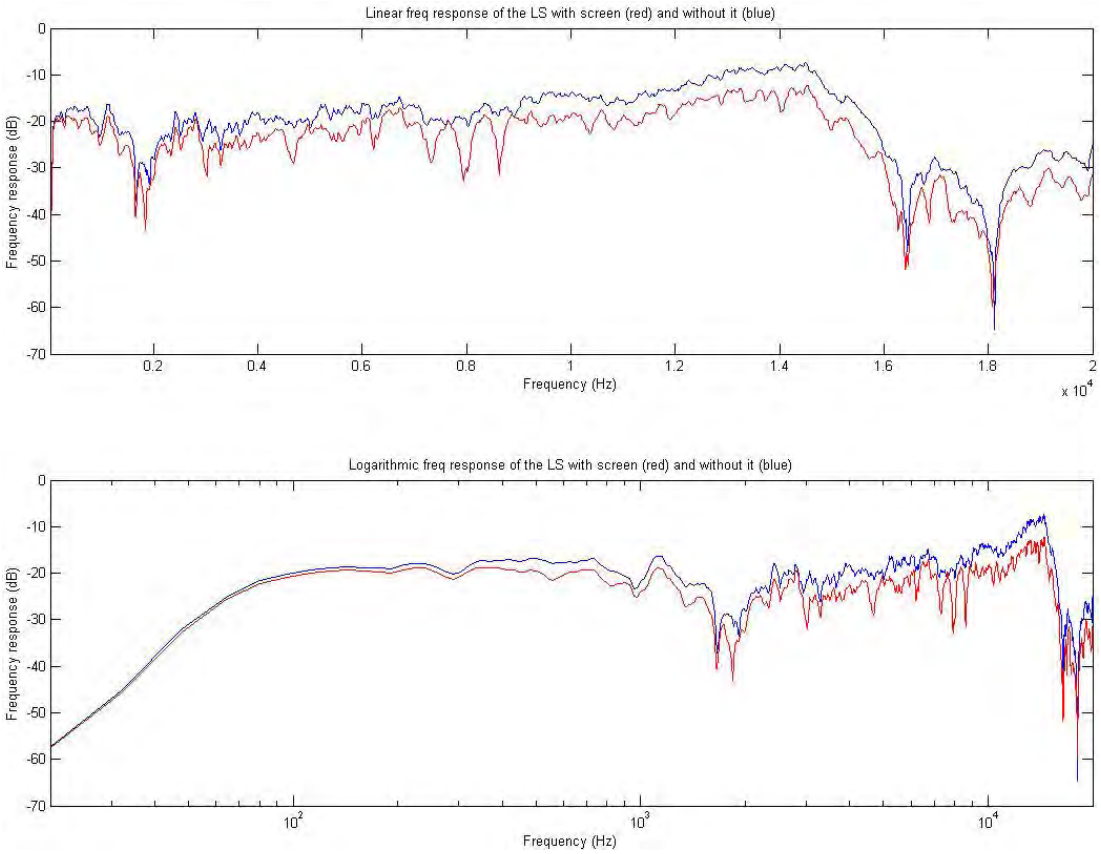

Fig. A. 95: Freq. response for ClearPix 2 White 1.0 with screen angled 25 degrees. Mic position 30 deg

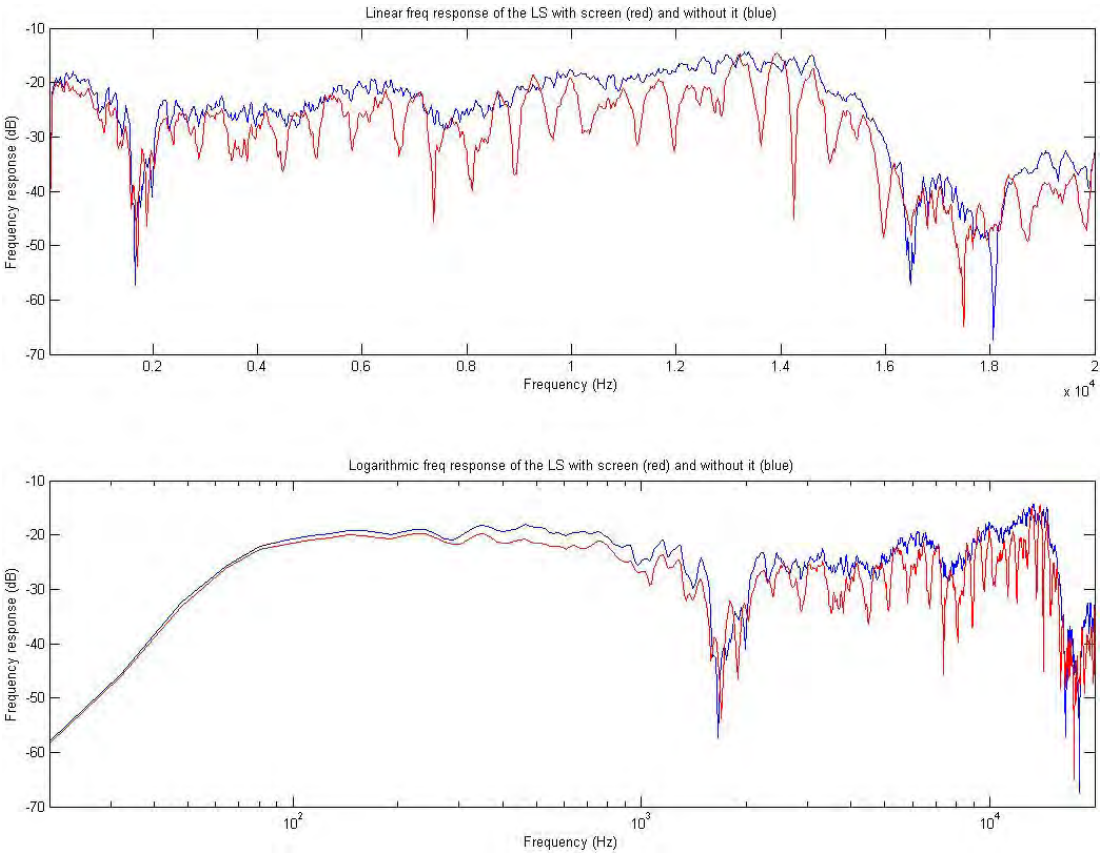

Fig. A. 96: Freq. response for ClearPix 2 White 1.0 with screen angled 25 degrees. Mic position 45 deg

Appendix B

Attenuation

B. 1. Enlightor 4K

Attenuation for screen Enlightor 4K at a distance of 2 cm

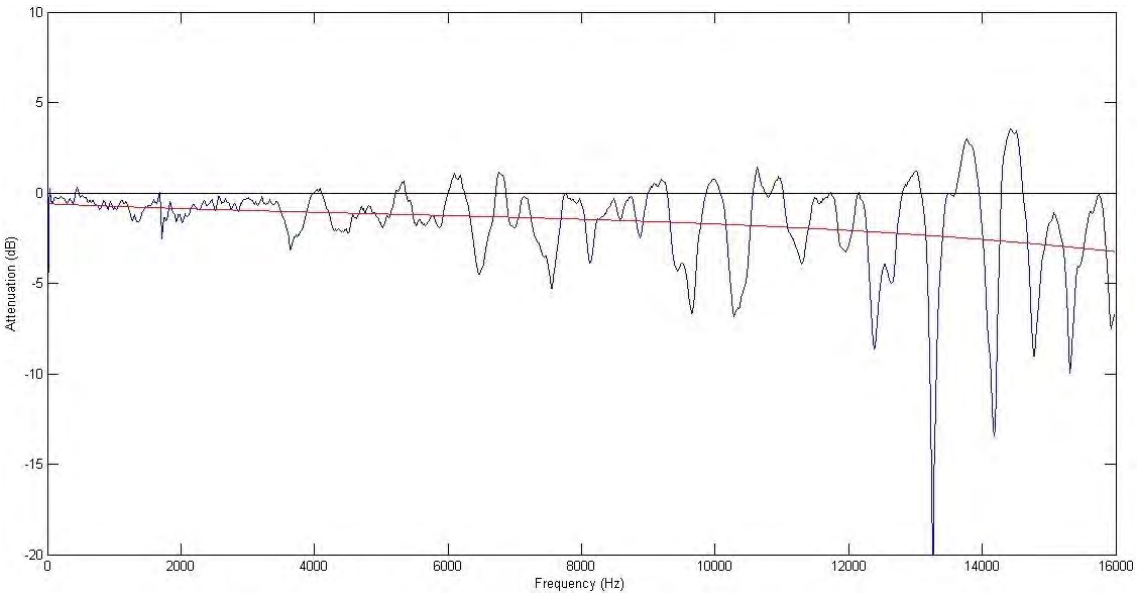

Fig. B. 1: Attenuation for Enlightor 4K at a distance of 2 cm. 0 degrees

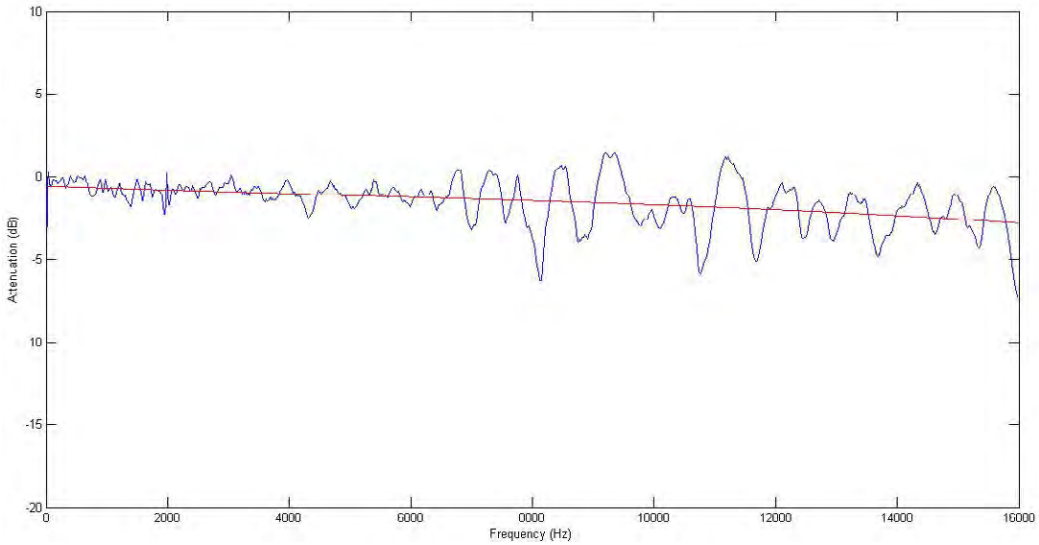

Fig. B. 2: Attenuation for Enlightor 4K at a distance of 2 cm. 15 degrees

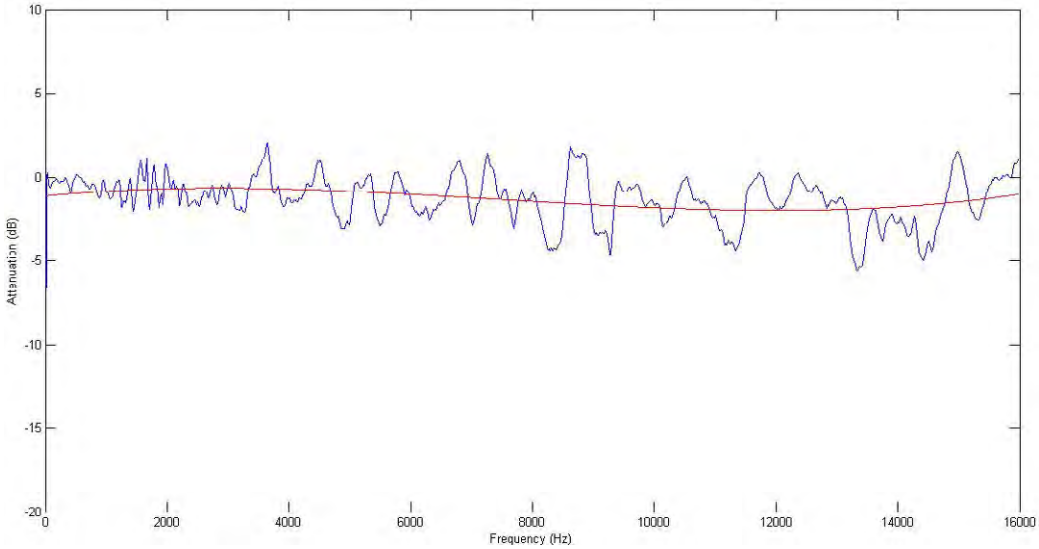

Fig. B. 3: Attenuation for Enlightor 4K at a distance of 2 cm. 30 degrees

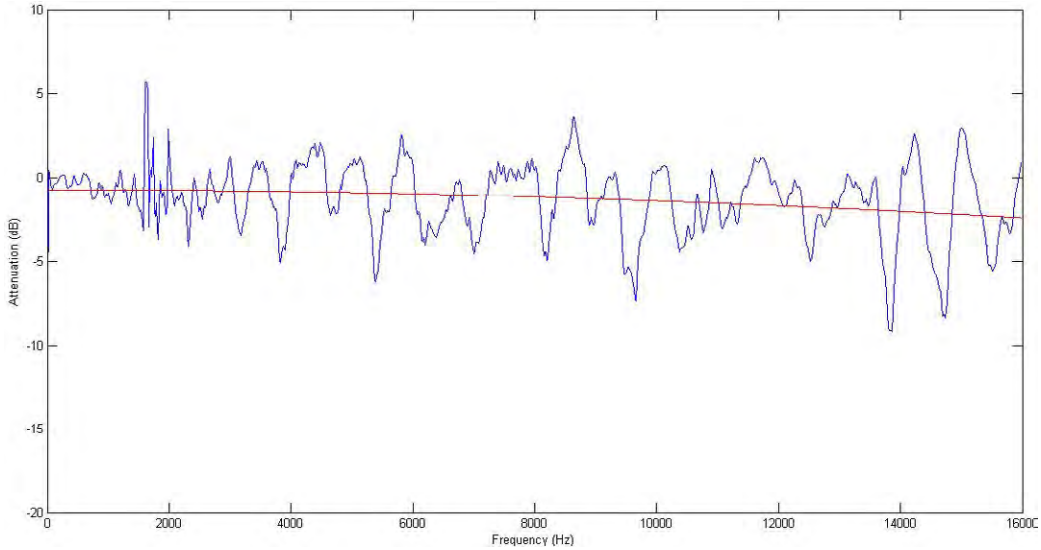

Fig. B. 4: Attenuation for Enlightor 4K at a distance of 2 cm. 45 degrees

Attenuation for screen Enlightor 4K at a distance of 7 cm

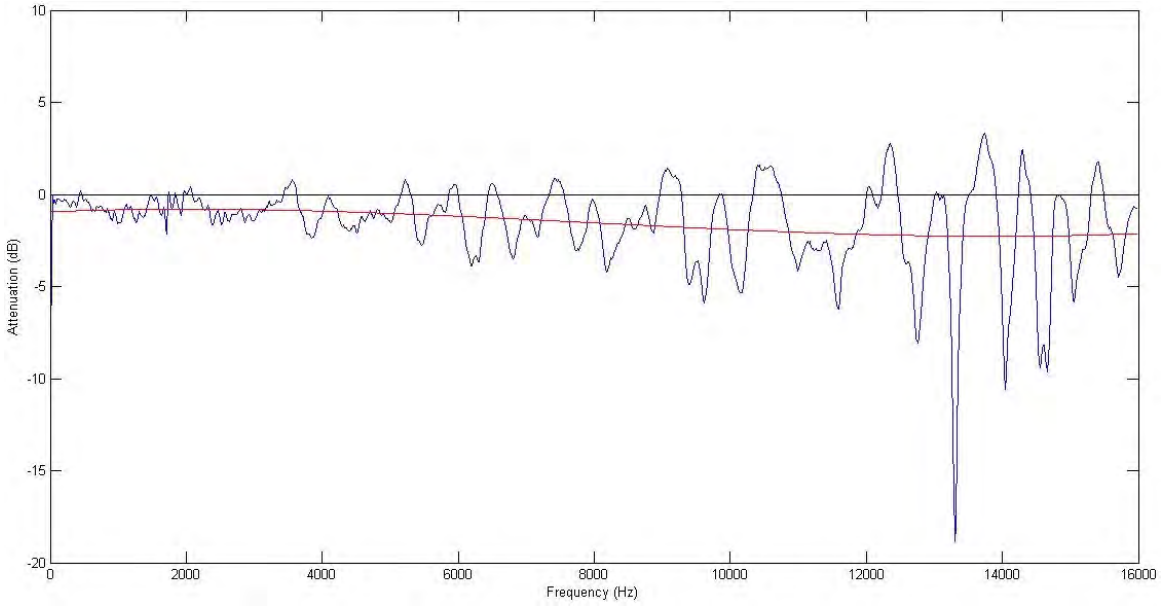

Fig. B. 5: Attenuation for Enlightor 4K at a distance of 7 cm. 0 degrees

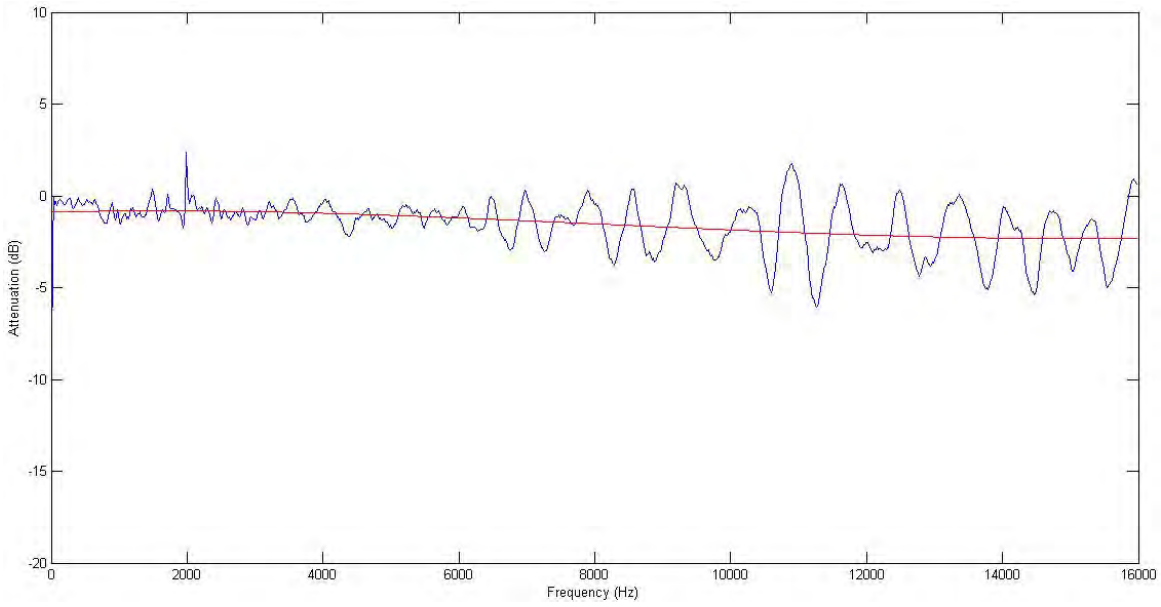

Fig. B. 6: Attenuation for Enlightor 4K at a distance of 7 cm. 15 degrees

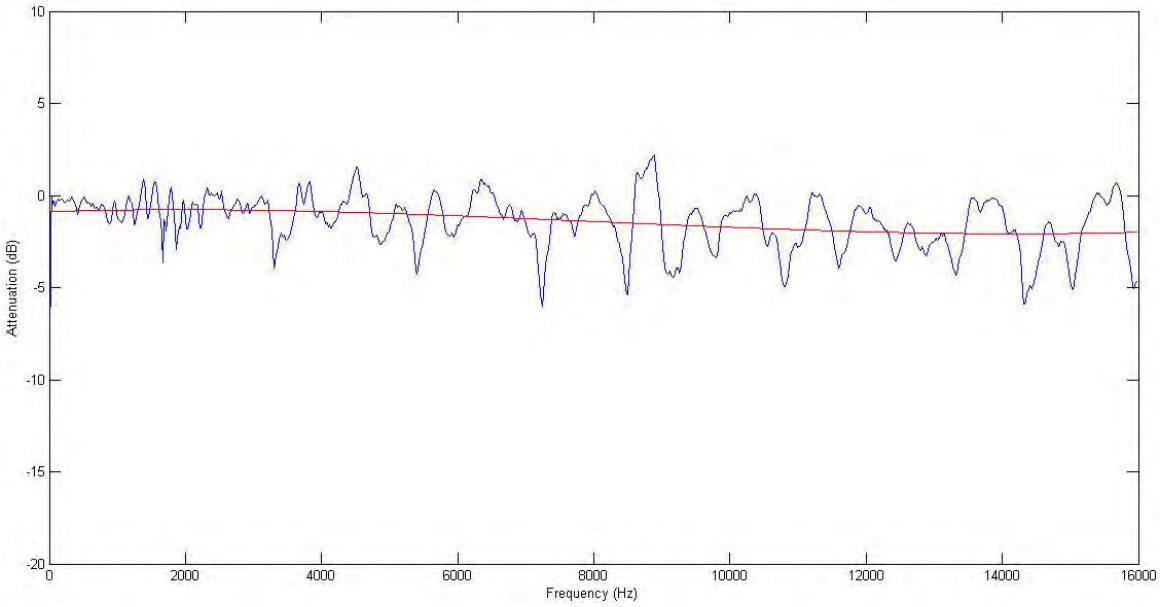

Fig. B. 7: Attenuation for Enlightor 4K at a distance of 7 cm. 30 degrees

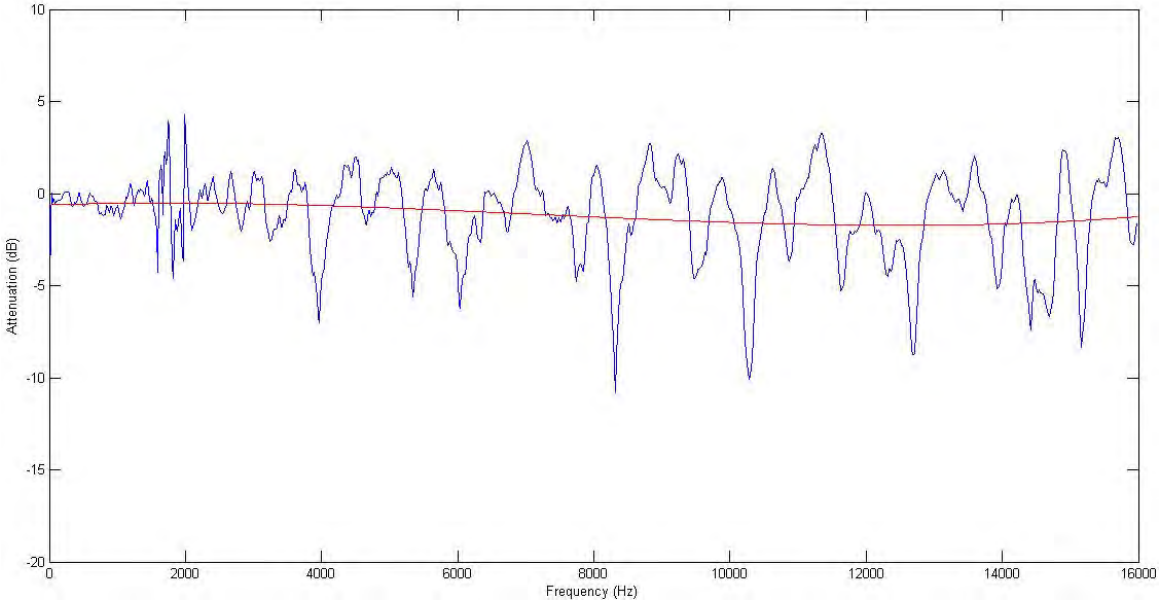

Fig. B. 8: Attenuation for Enlightor 4K at a distance of 7 cm. 45 degrees

Attenuation for screen Enlightor 4K at a distance of 15 cm

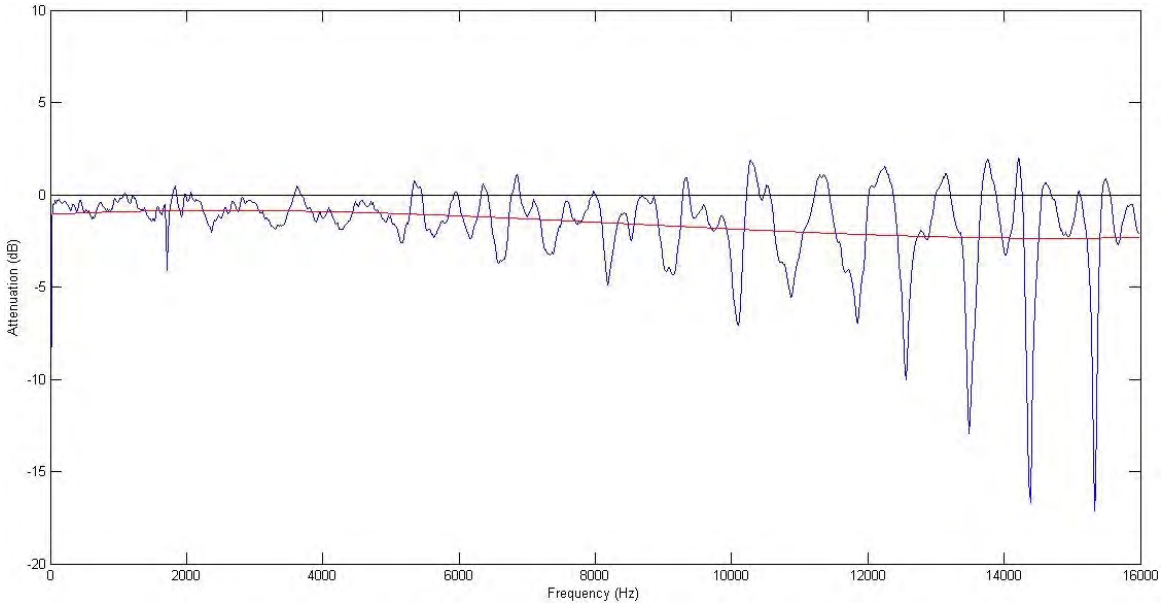

Fig. B. 9: Attenuation for Enlightor 4K at a distance of 15 cm. 0 degrees

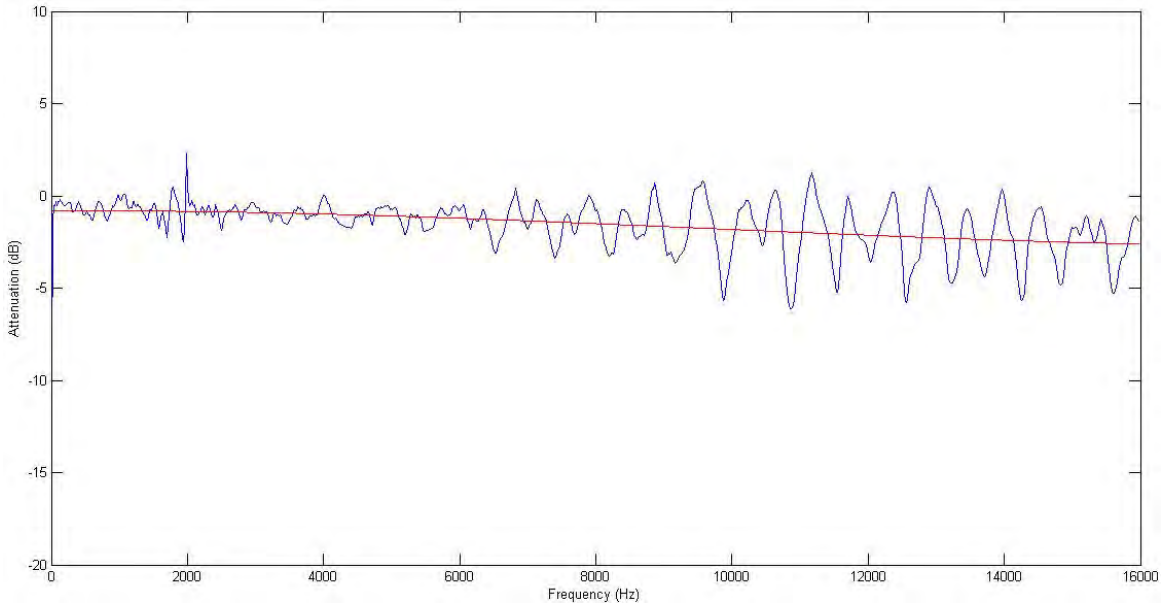

Fig. B. 10: Attenuation for Enlightor 4K at a distance of 15 cm. 15 degrees

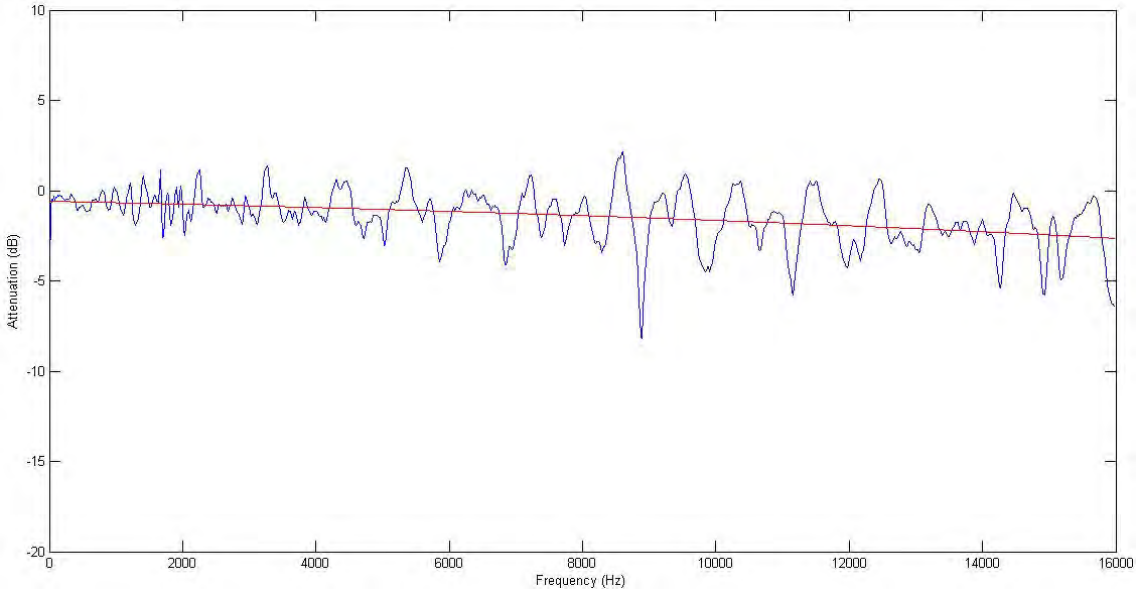

Fig. B. 11: Attenuation for Enlightor 4K at a distance of 15 cm. 30 degrees

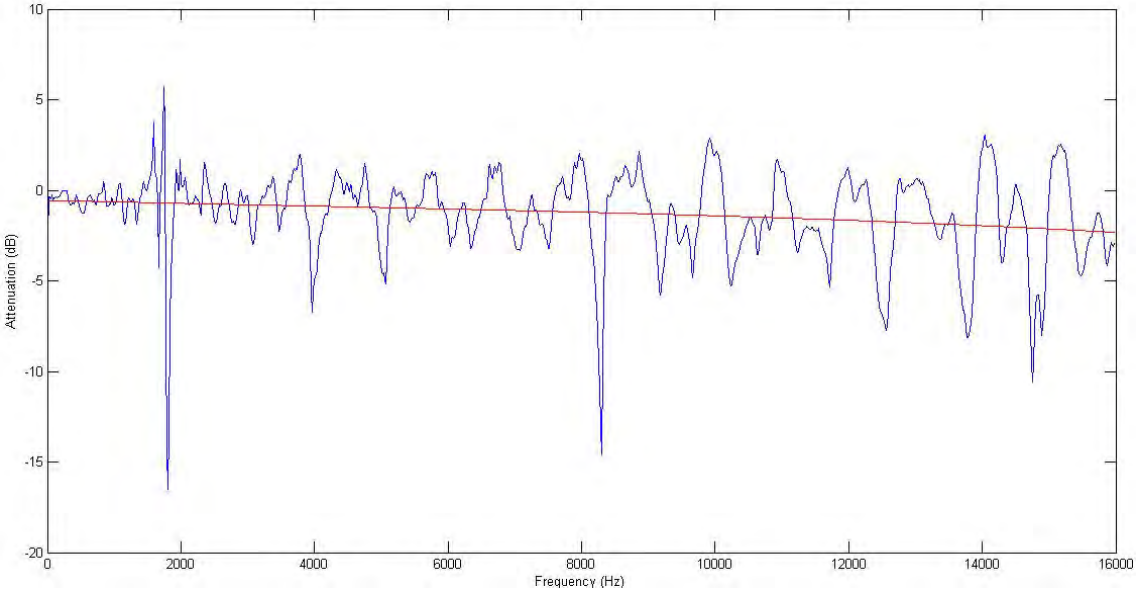

Fig. B. 12: Attenuation for Enlightor 4K at a distance of 15 cm. 45 degrees

Attenuation for screen Enlightor 4K at a distance of 30 cm

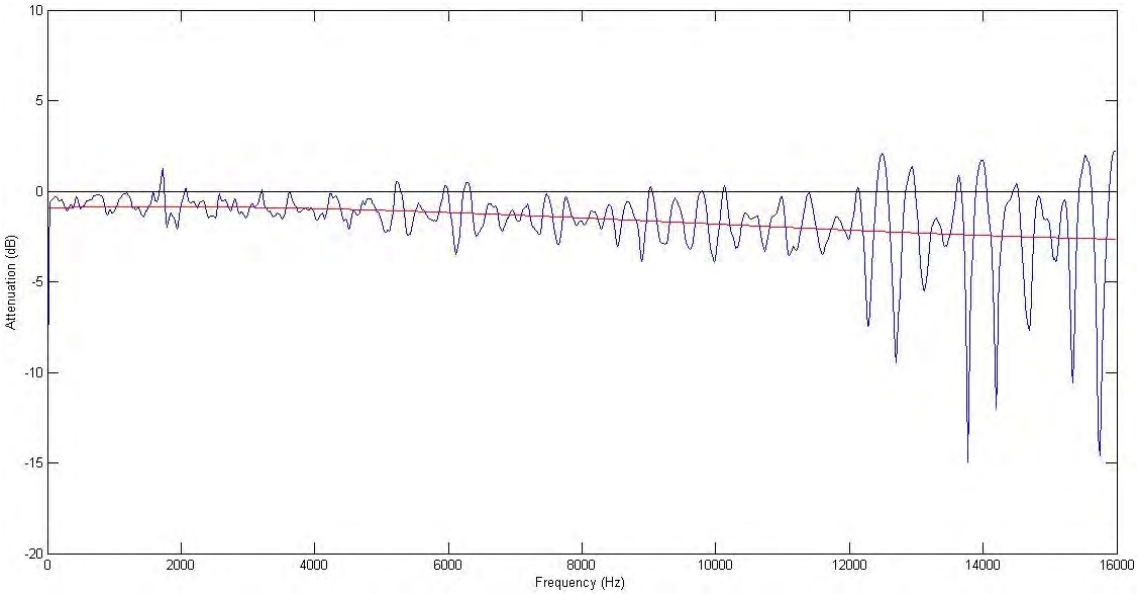

Fig. B. 13: Attenuation for Enlightor 4K at a distance of 30 cm. 0 degrees

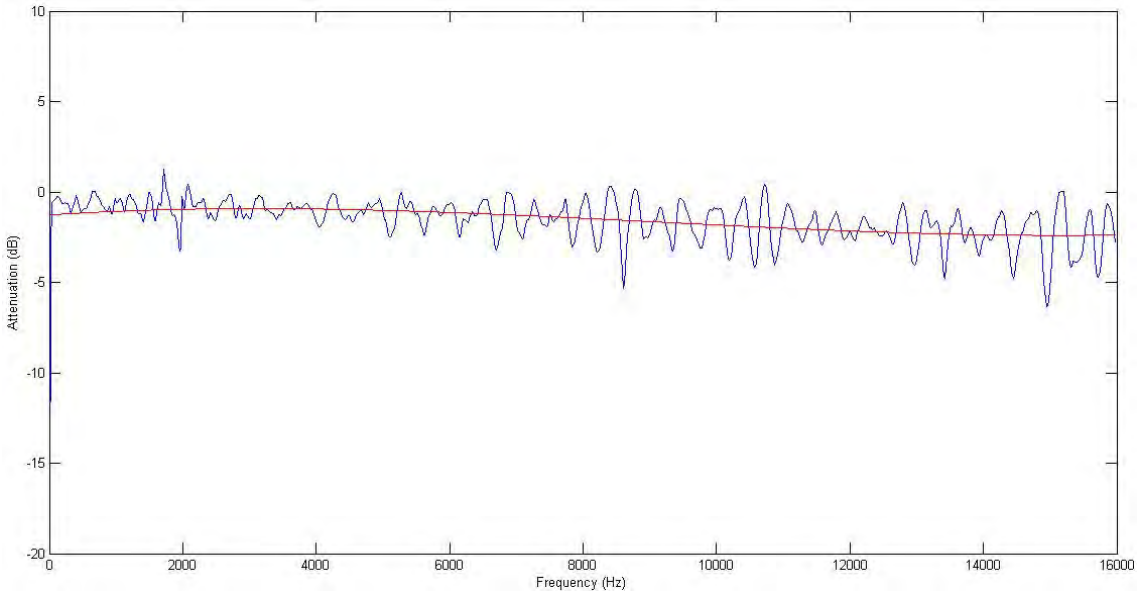

Fig. B. 14: Attenuation for Enlightor 4K at a distance of 30 cm. 15 degrees

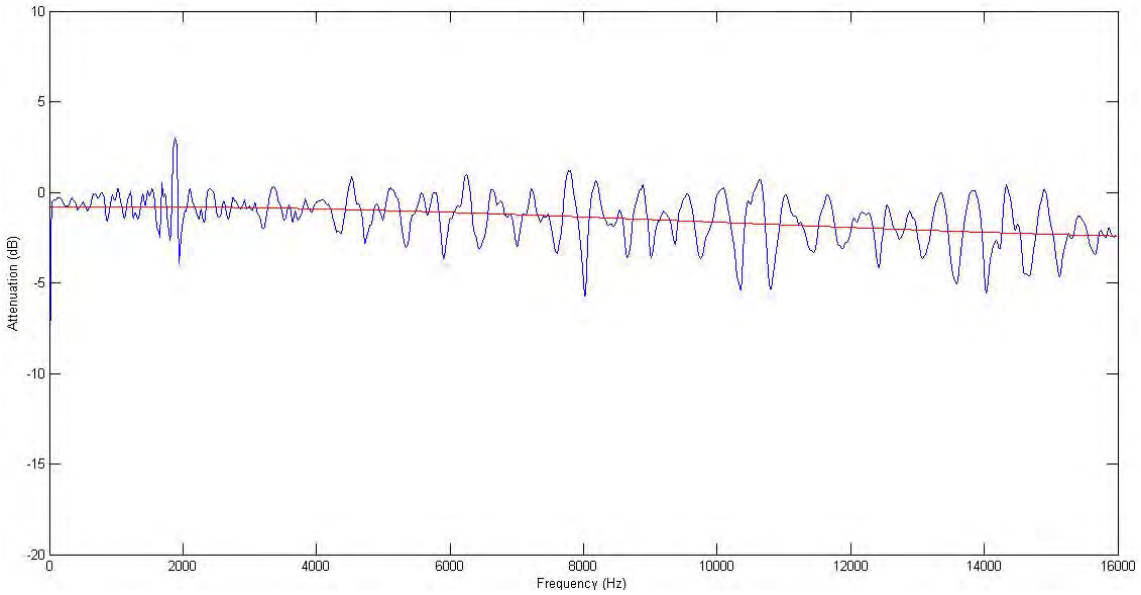

Fig. B. 15: Attenuation for Enlightor 4K at a distance of 30 cm. 30 degrees

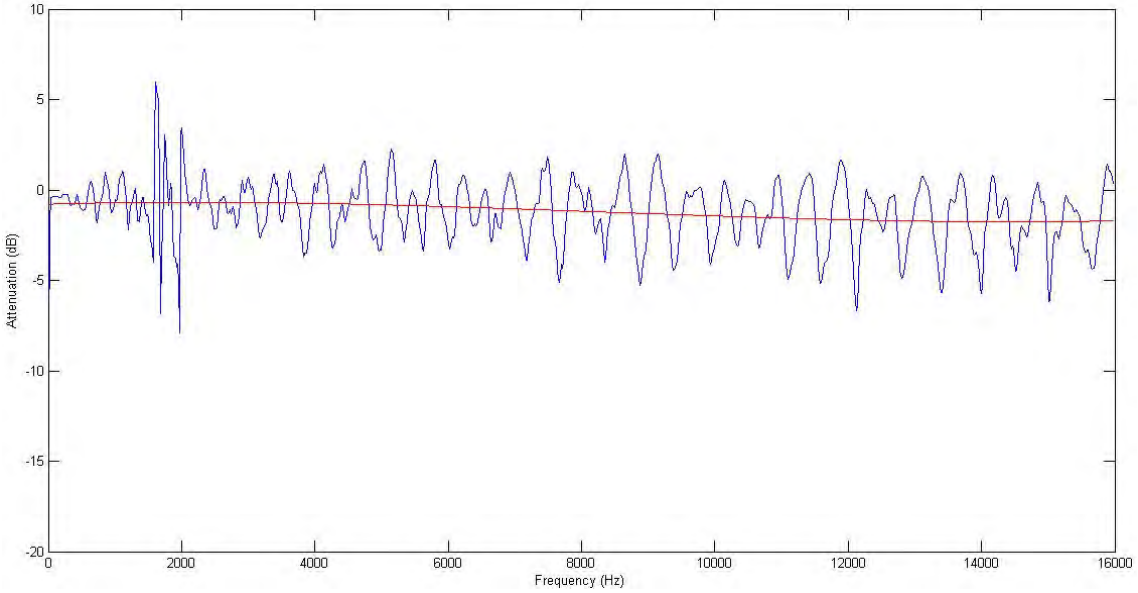

Fig. B. 16: Attenuation for Enlightor 4K at a distance of 30 cm. 45 degrees

Attenuation for screen Enlightor 4K at a distance of 45 cm

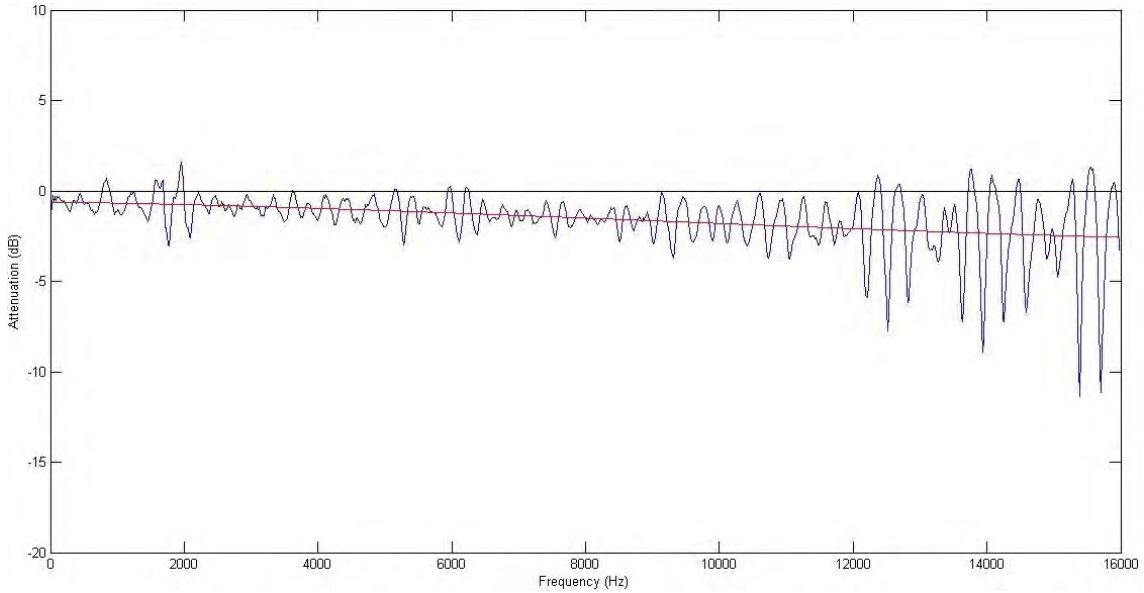

Fig. B. 17: Attenuation for Enlightor 4K at a distance of 45 cm. 0 degrees

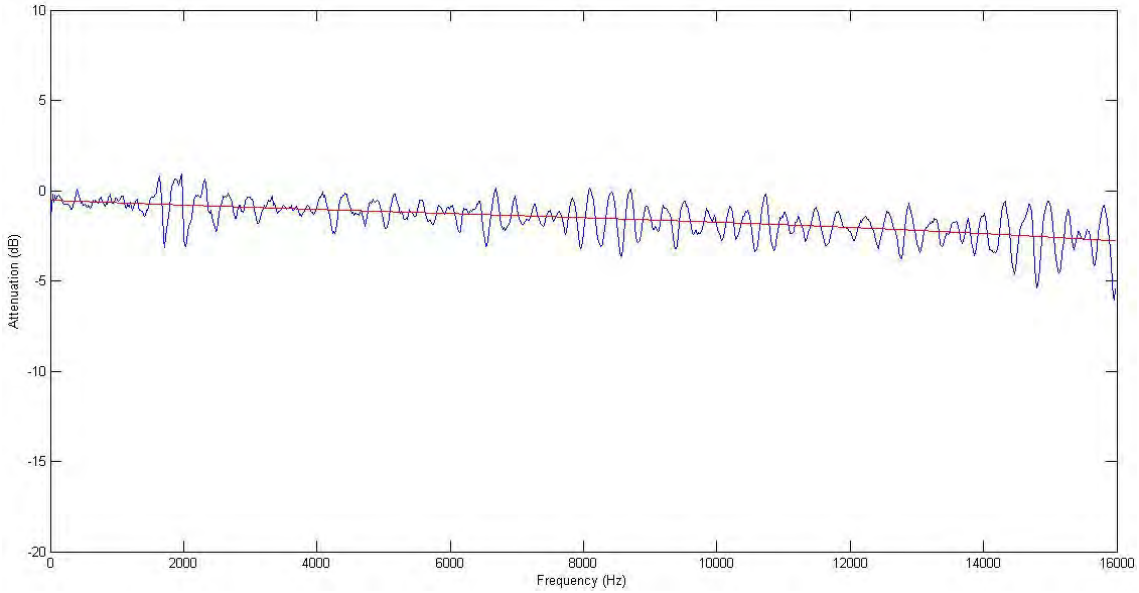

Fig. B. 18: Attenuation for Enlightor 4K at a distance of 45 cm. 15 degrees

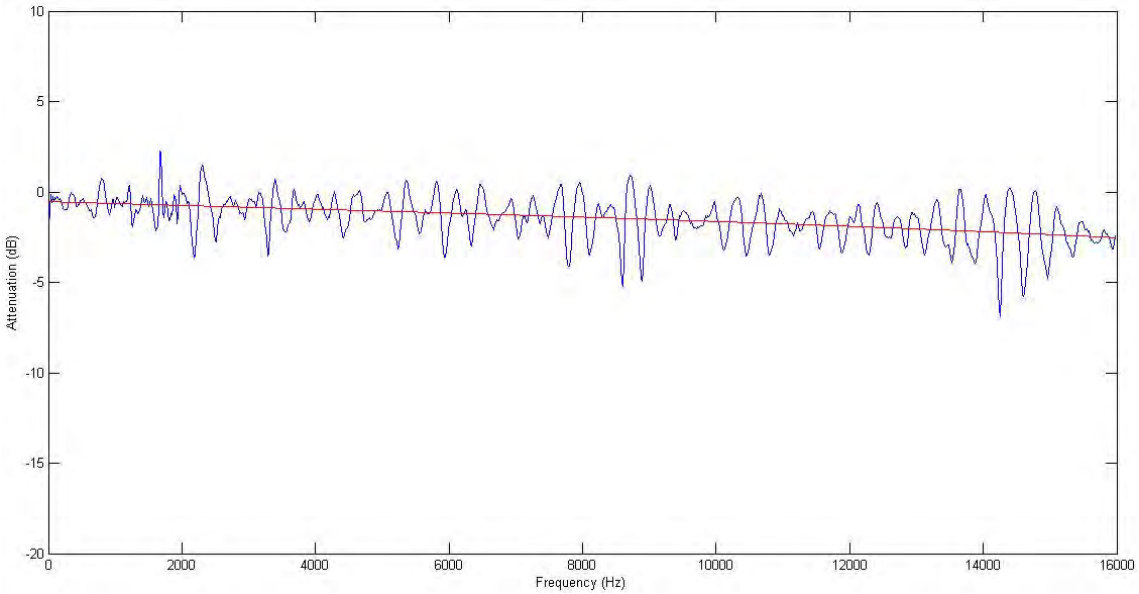

Fig. B. 19: Attenuation for Enlightor 4K at a distance of 45 cm. 30 degrees

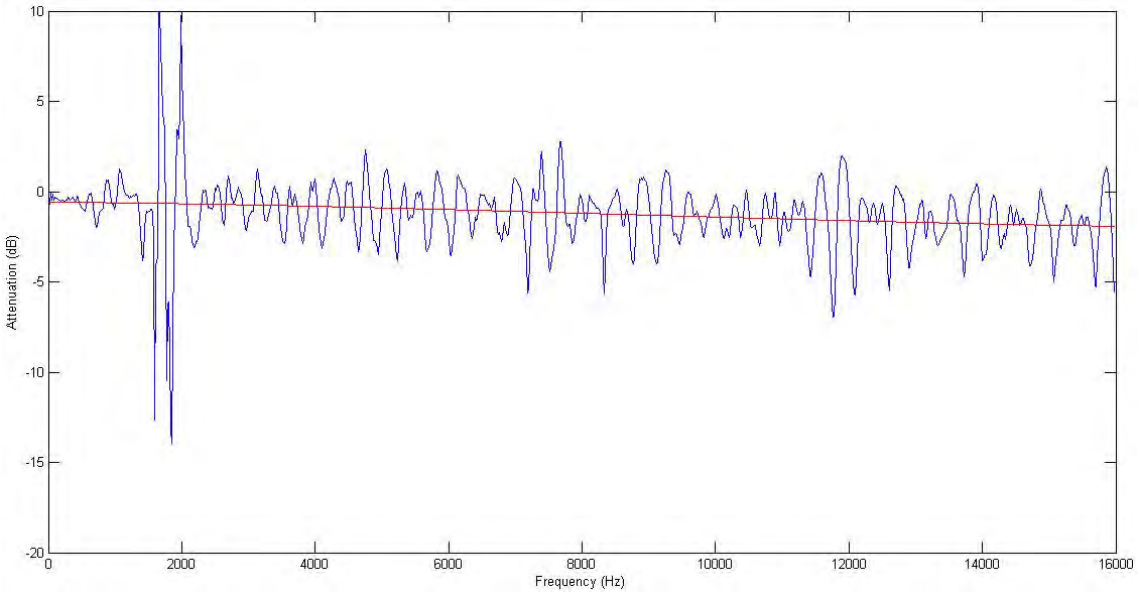

Fig. B. 20: Attenuation for Enlightor 4K at a distance of 45 cm. 45 degrees

Attenuation for screen Enlightor 4K at a distance of 60 cm

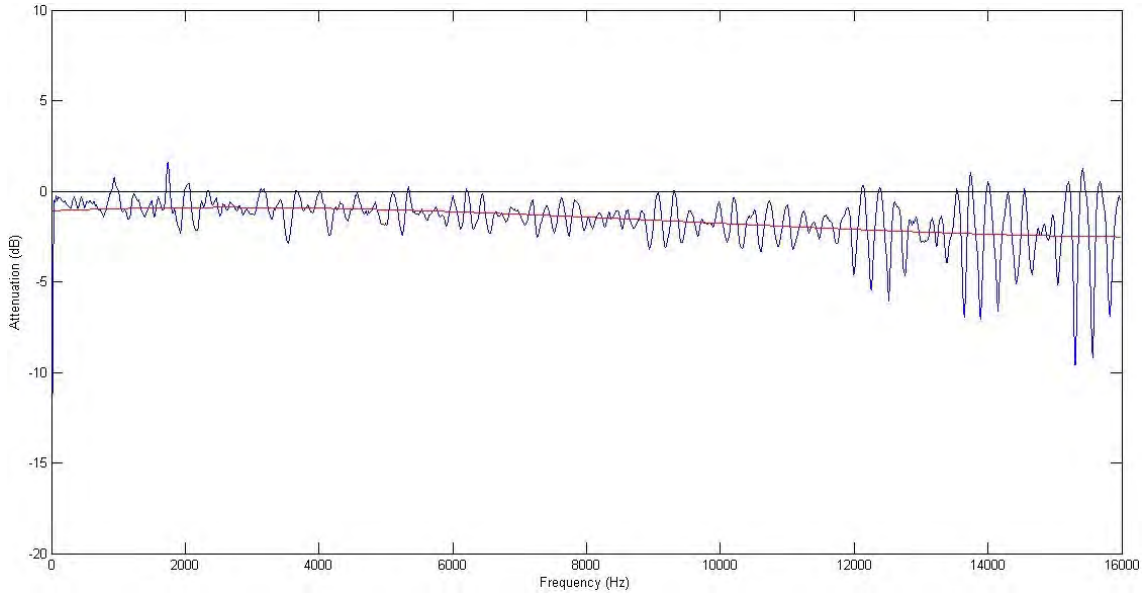

Fig. B. 21: Attenuation for Enlightor 4K at a distance of 60 cm. 0 degrees

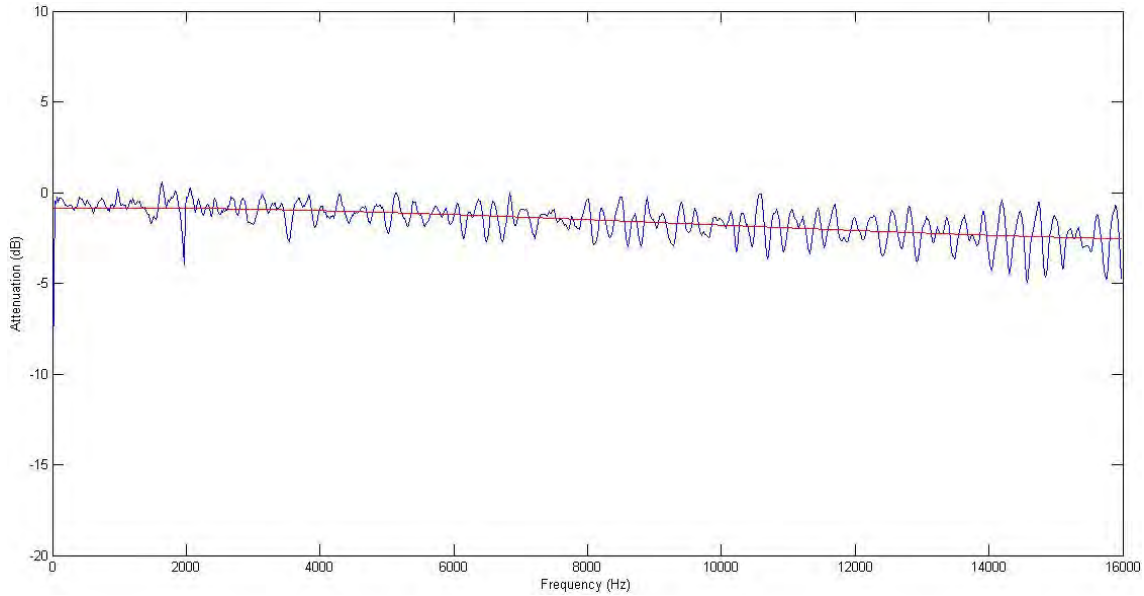

Fig. B. 22: Attenuation for Enlightor 4K at a distance of 60 cm. 15 degrees

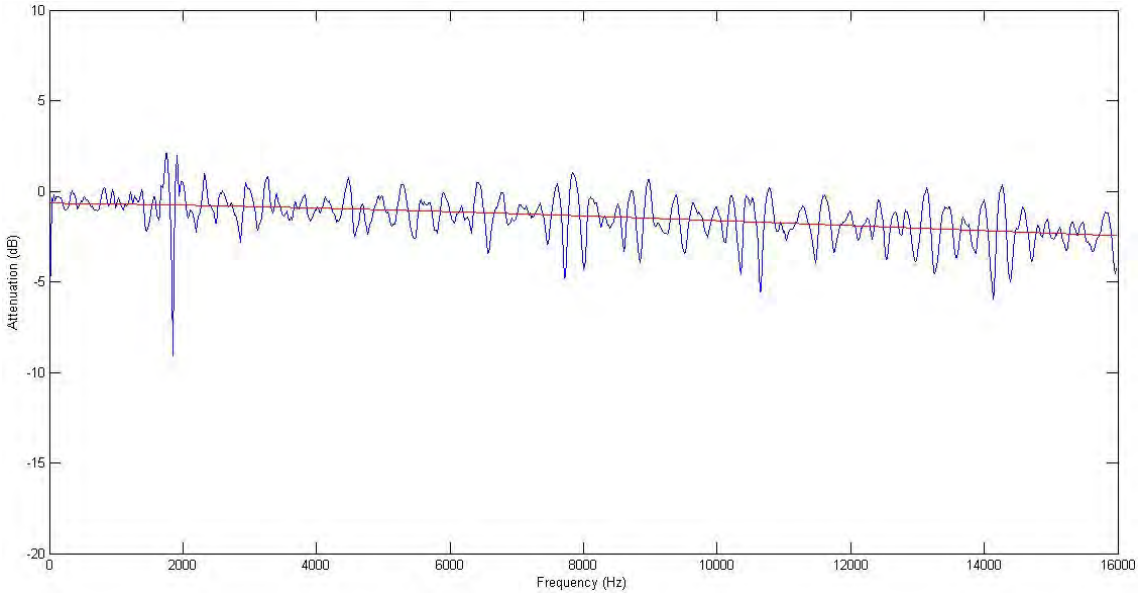

Fig. B. 23: Attenuation for Enlightor 4K at a distance of 60 cm. 30 degrees

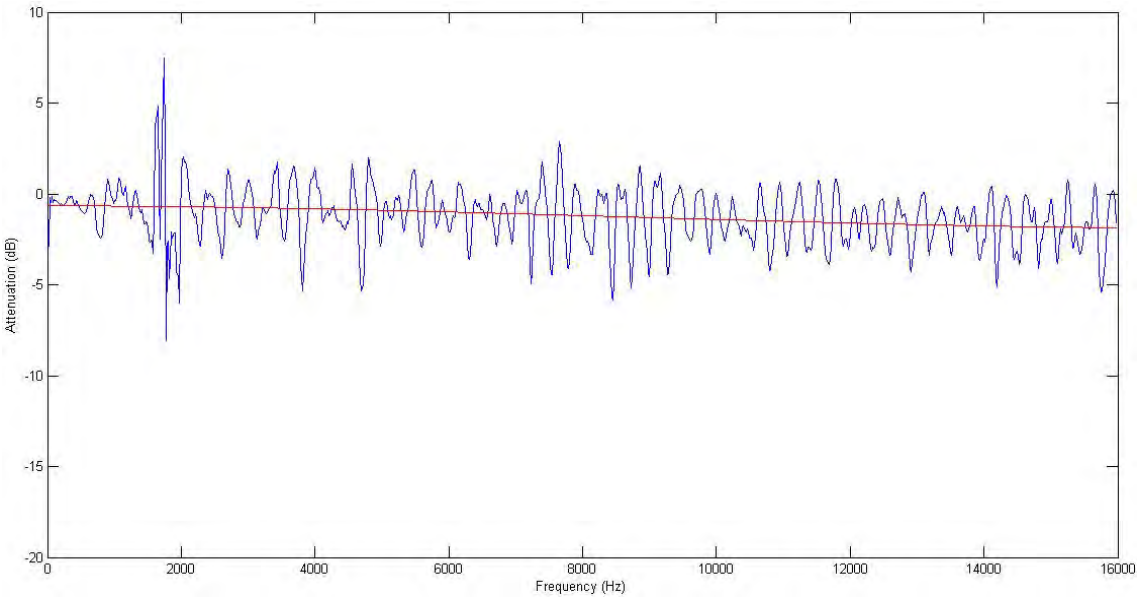

Fig. B. 24: Attenuation for Enlightor 4K at a distance of 60 cm. 45 degrees

Attenuation for screen Enlightor 4K with screen angled 10 deg

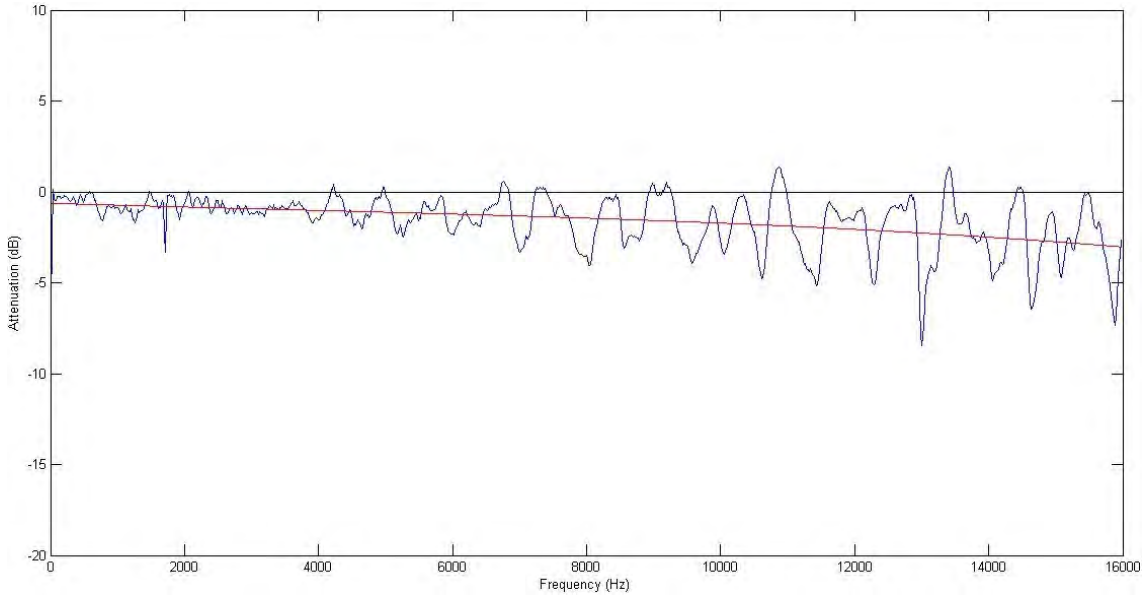

Fig. B. 25: Attenuation for screen Enlightor 4K with screen angled 10 degrees. Mic position 0 deg

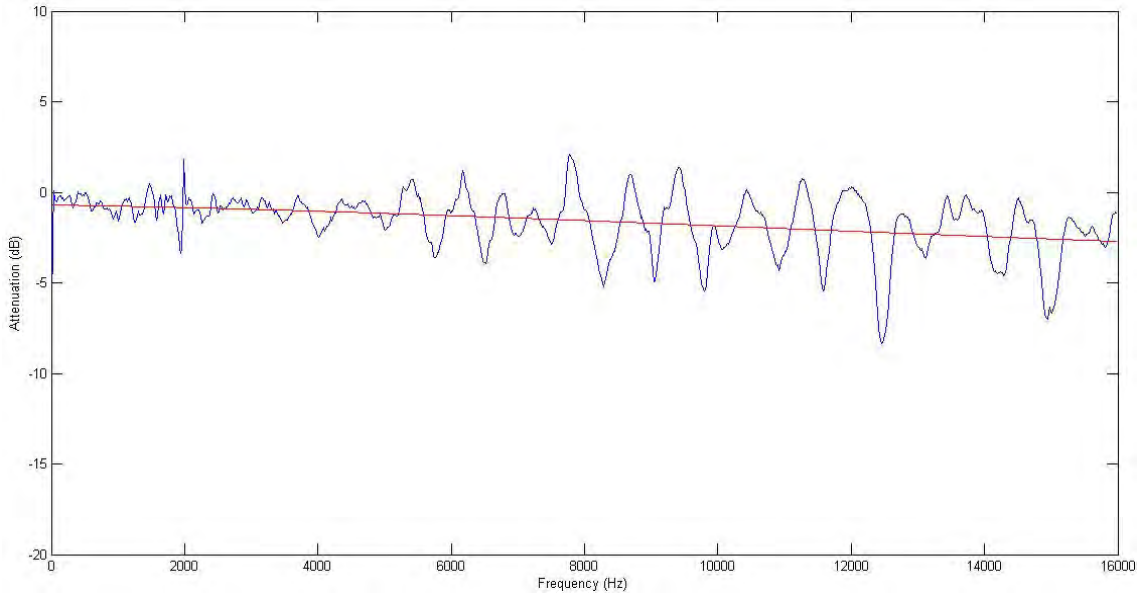

Fig. B. 26: Attenuation for screen Enlightor 4K with screen angled 10 degrees. Mic position 15 deg

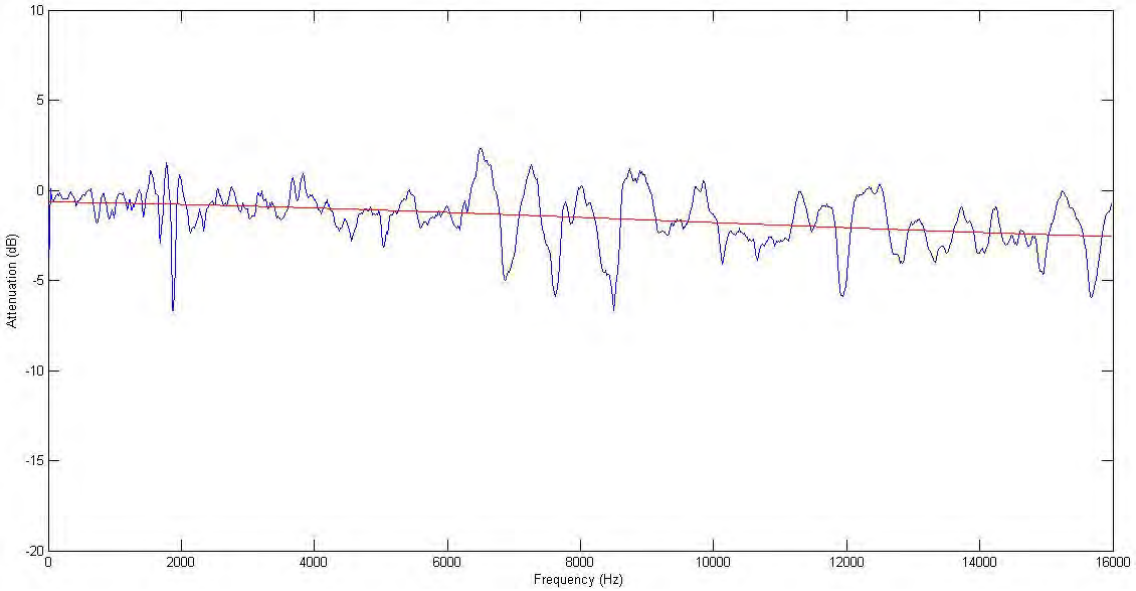

Fig. B. 27: Attenuation for screen Enlightor 4K with screen angled 10 degrees. Mic position 30 deg

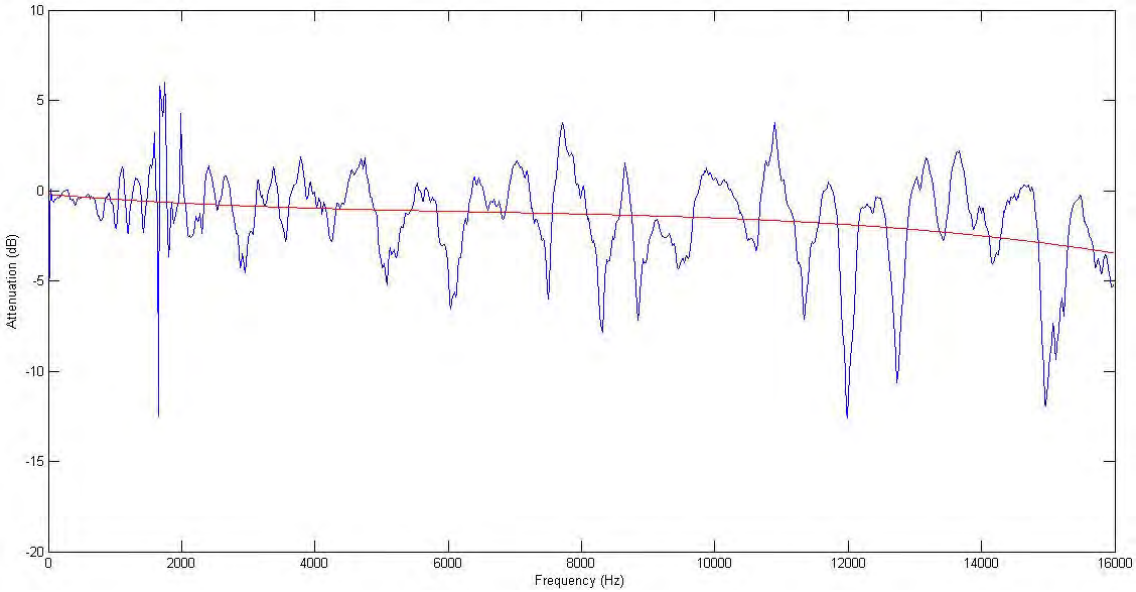

Fig. B. 28: Attenuation for screen Enlightor 4K with screen angled 10 degrees. Mic position 45 deg

Attenuation for screen Enlightor 4K with screen angled 25 deg

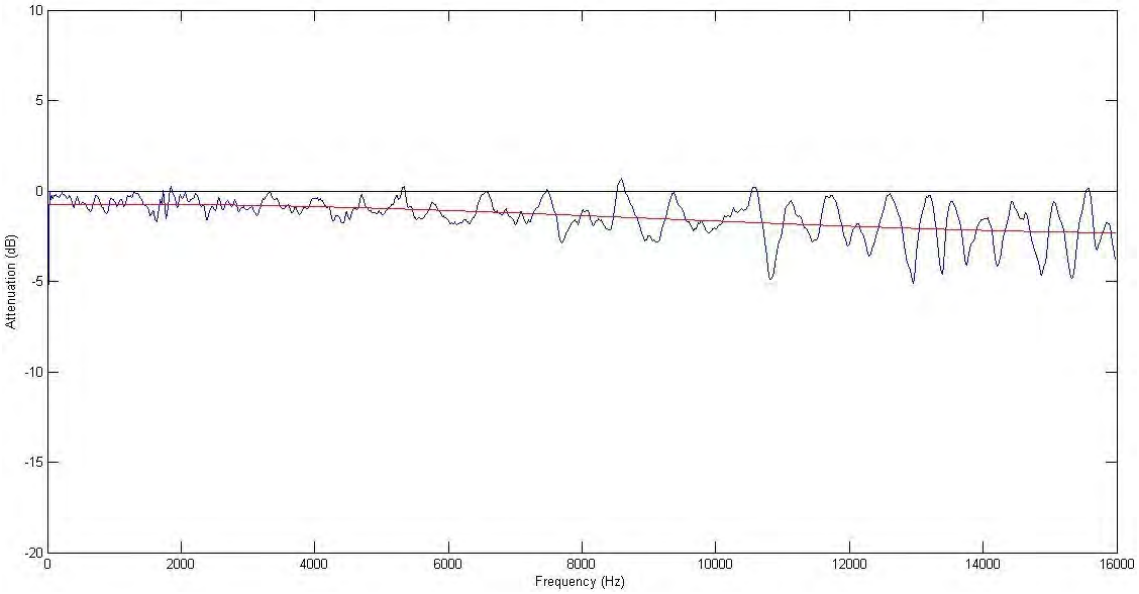

Fig. B. 29: Attenuation for screen Enlightor 4K with screen angled 25 degrees. Mic position 0 deg

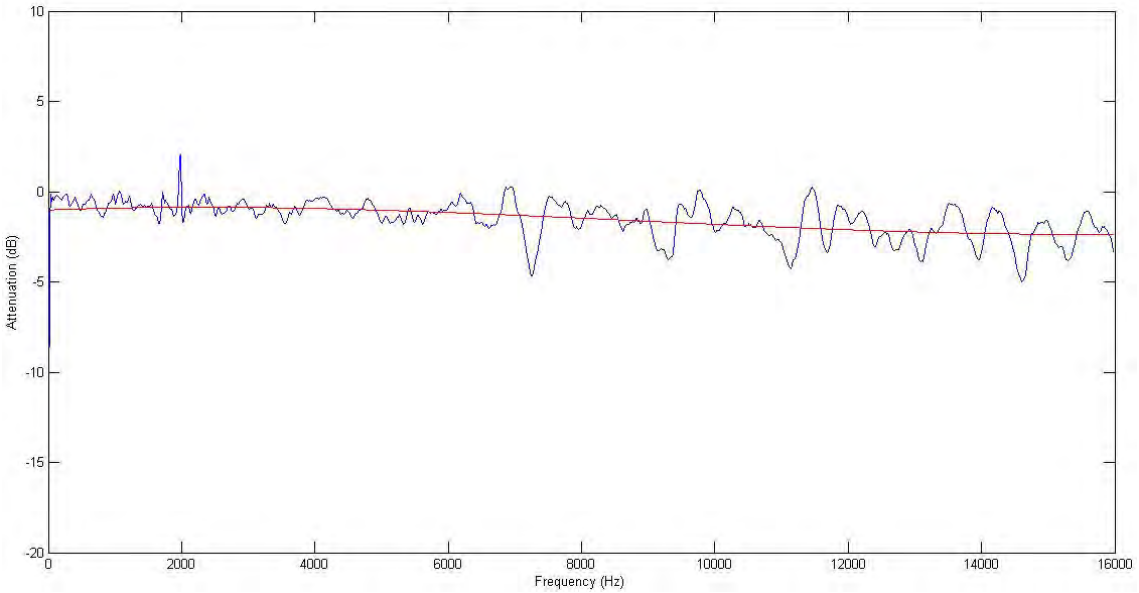

Fig. B. 30: Attenuation for screen Enlightor 4K with screen angled 25 degrees. Mic position 15 deg

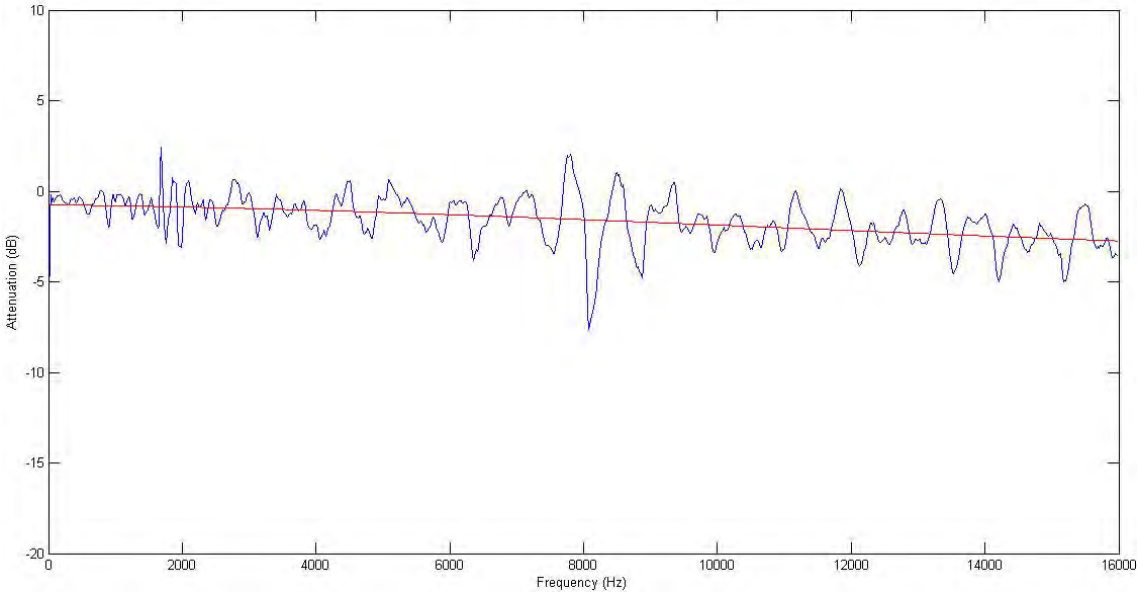

Fig. B. 31: Attenuation for screen Enlightor 4K with screen angled 25 degrees. Mic position 30 deg

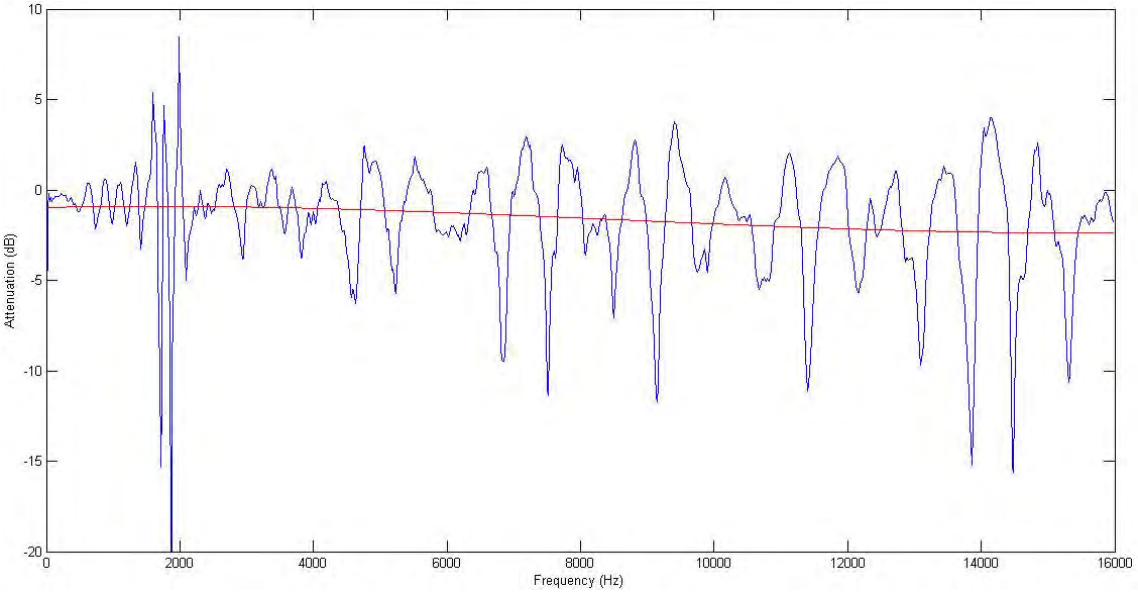

Fig. B. 32: Attenuation for screen Enlightor 4K with screen angled 25 degrees. Mic position 45 deg

B. 2. Matt Plus Miniperforated

Attenuation for screen Matt Plus Miniperforated at a distance of 2 cm

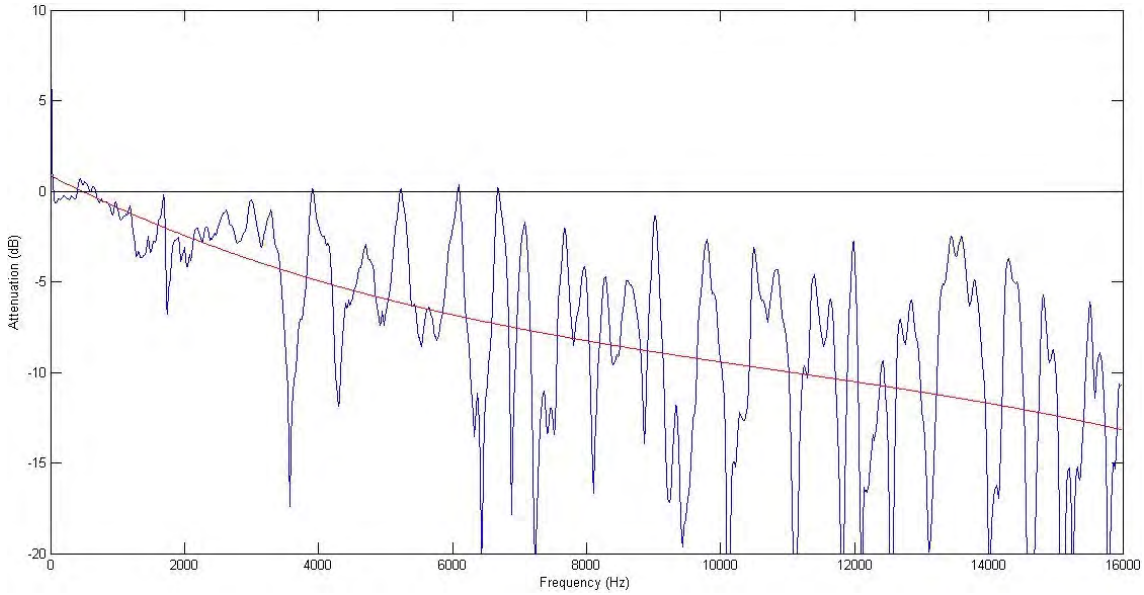

Fig. B. 33: Attenuation for Matt Plus Miniperforated at a distance of 2 cm. 0 degrees

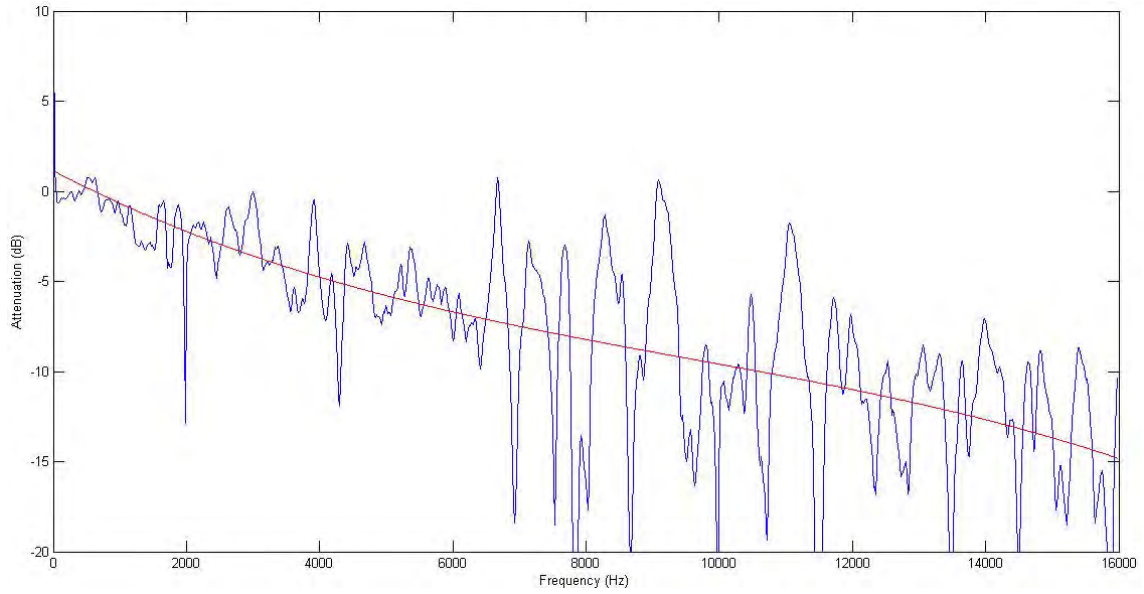

Fig. B. 34: Attenuation for Matt Plus Miniperforated at a distance of 2 cm. 15 degrees

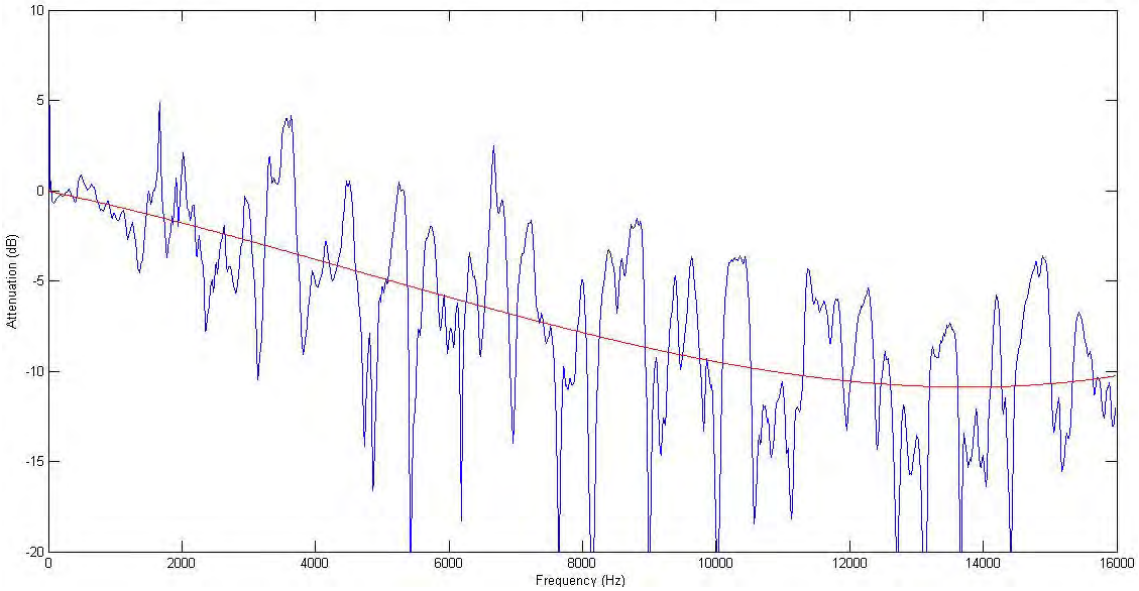

Fig. B. 35: Attenuation for Matt Plus Miniperforated at a distance of 2 cm. 30 degrees

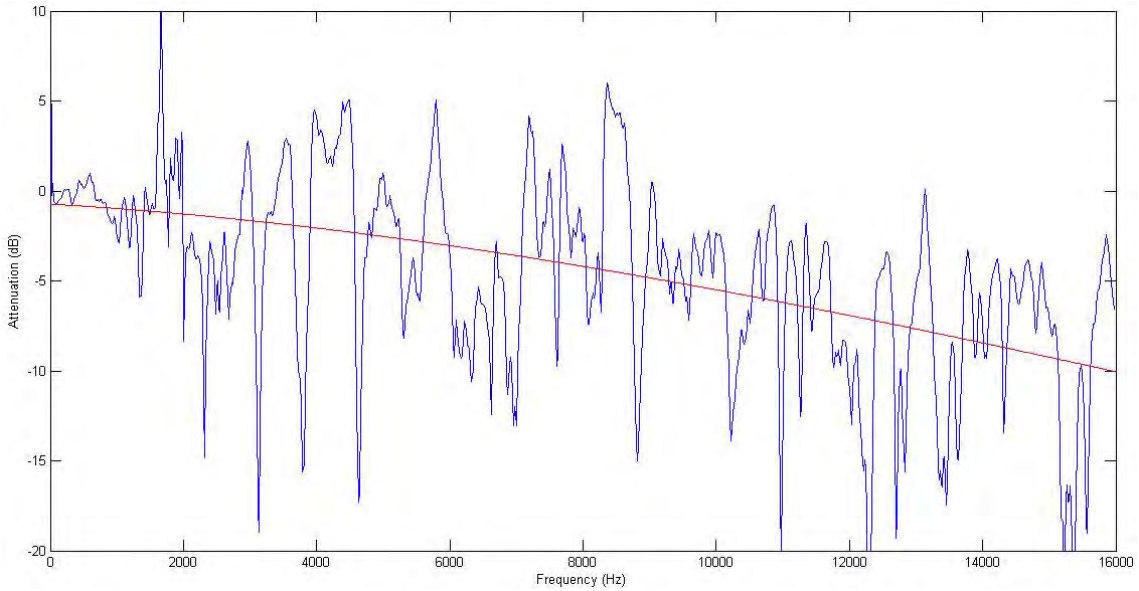

Fig. B. 36: Attenuation for Matt Plus Miniperforated at a distance of 2 cm. 45 degrees

Attenuation for screen Matt Plus Miniperforated at a distance of 7 cm

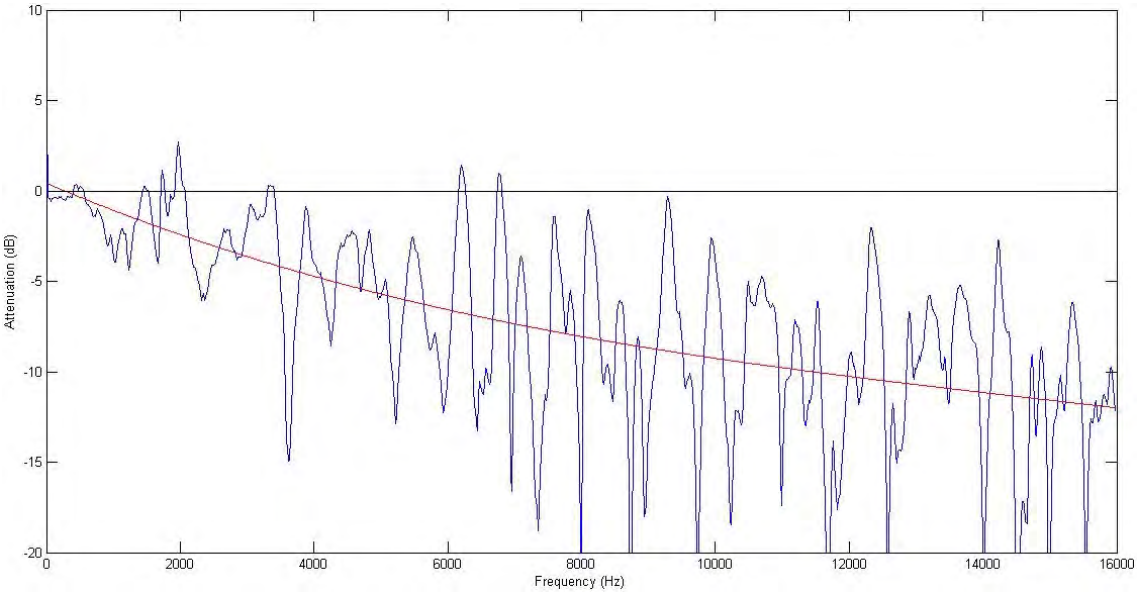

Fig. B. 37: Attenuation for Matt Plus Miniperforated at a distance of 7 cm. 0 degrees

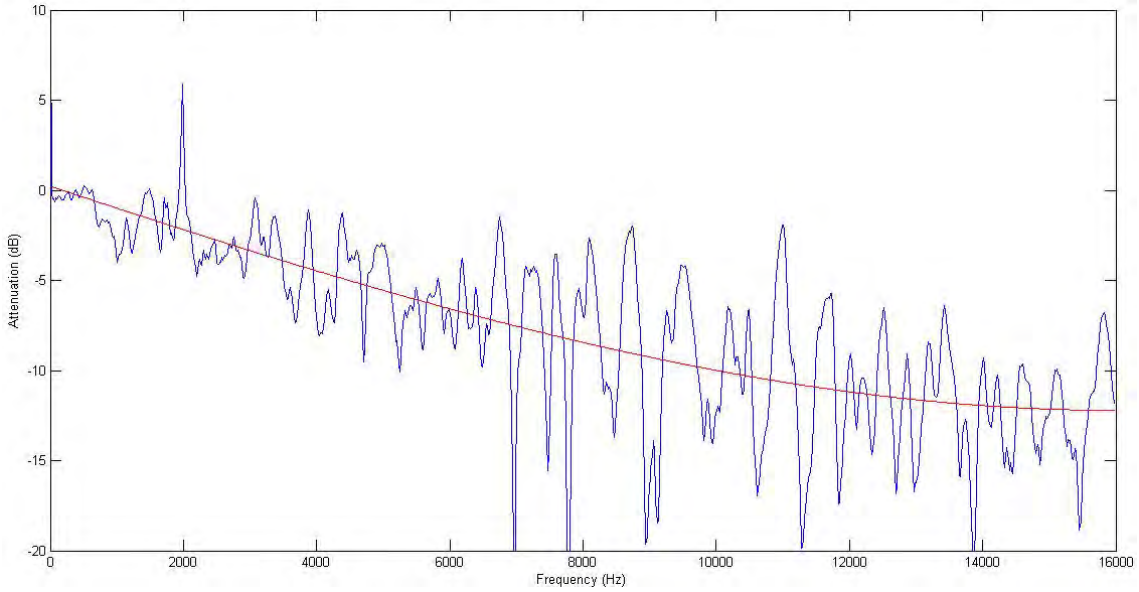

Fig. B. 38: Attenuation for Matt Plus Miniperforated at a distance of 7 cm. 15 degrees

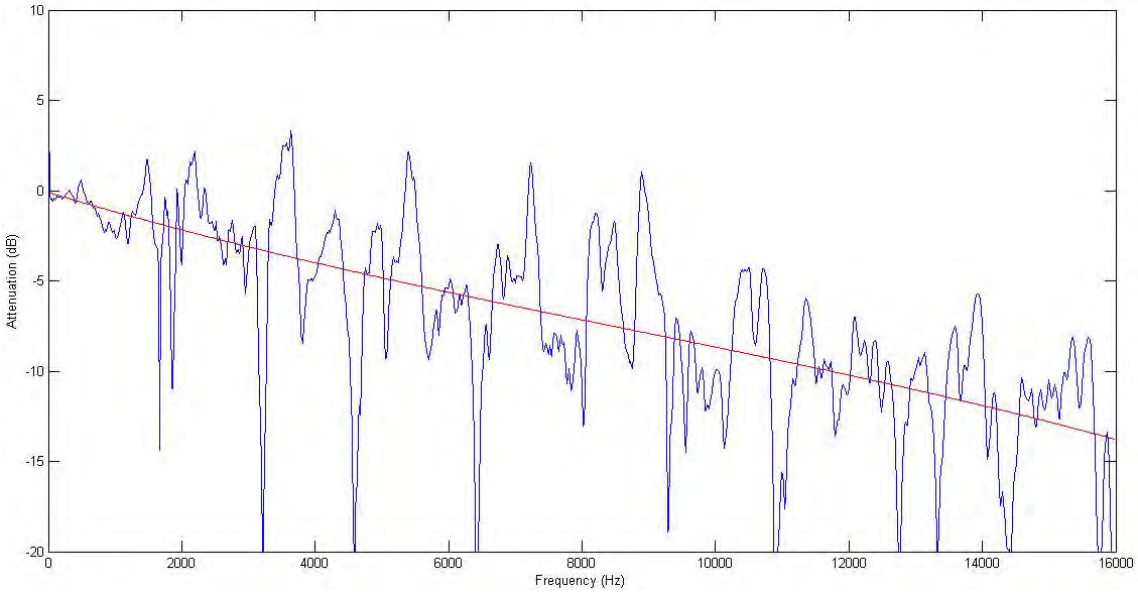

Fig. B. 39: Attenuation for Matt Plus Miniperforated at a distance of 7 cm. 30 degrees

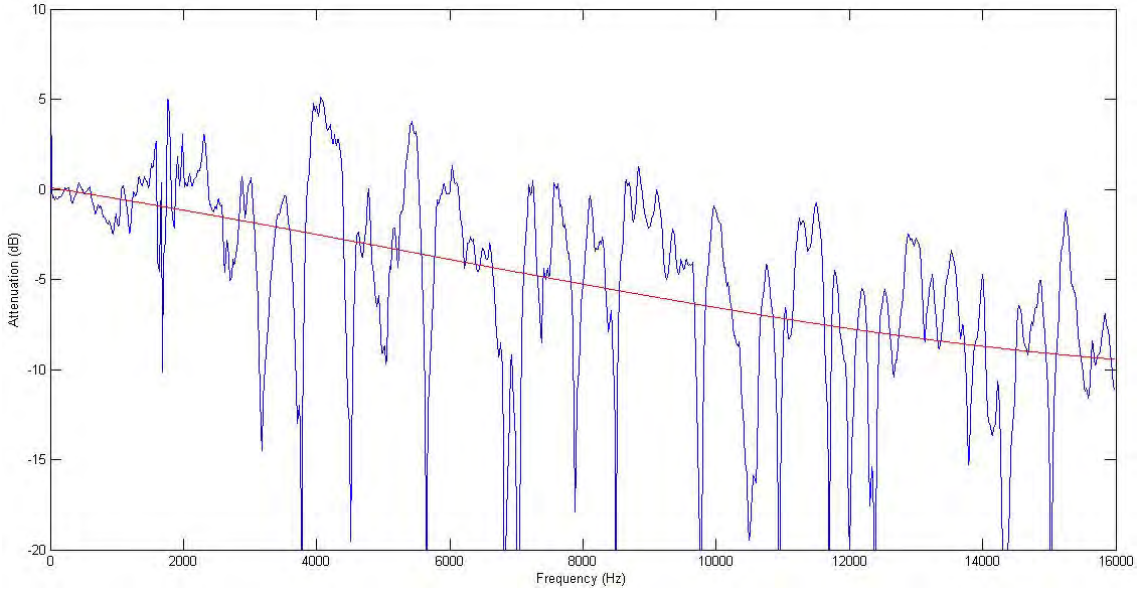

Fig. B. 40: Attenuation for Matt Plus Miniperforated at a distance of 7 cm. 45 degrees

Attenuation for screen Matt Plus Miniperforated at a distance of 15 cm

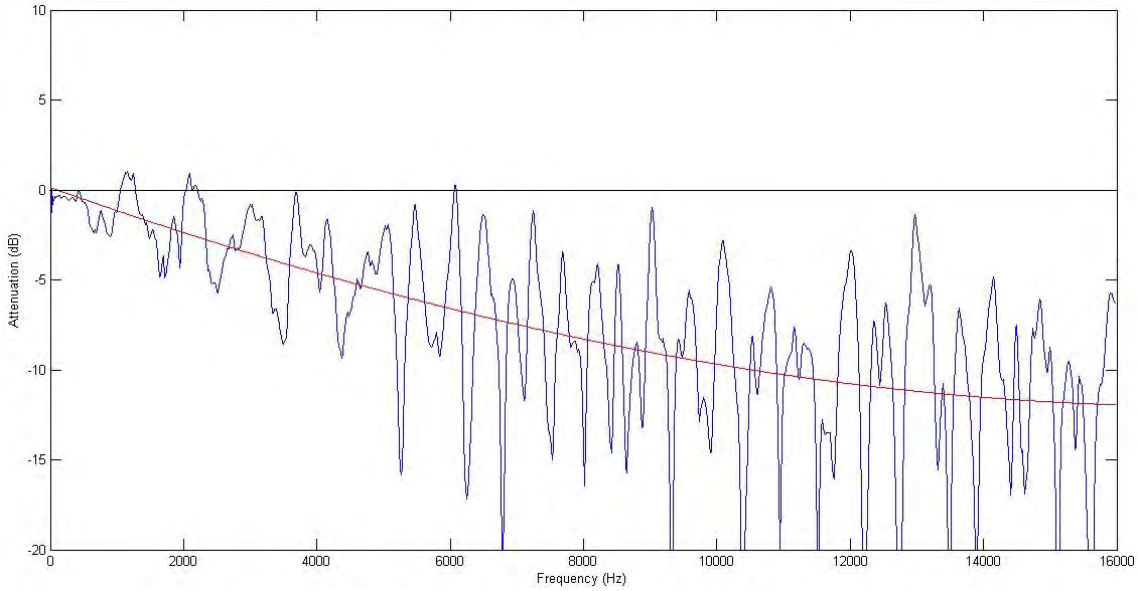

Fig. B. 41: Attenuation for Matt Plus Miniperforated at a distance of 15 cm. 0 degrees

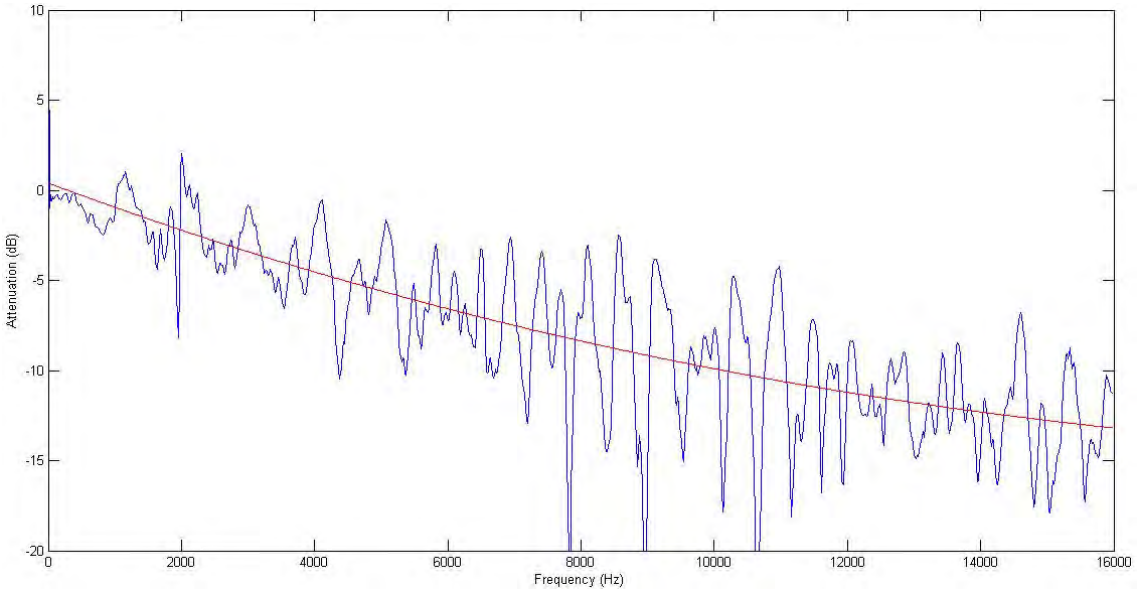

Fig. B. 42: Attenuation for Matt Plus Miniperforated at a distance of 15 cm. 15 degrees

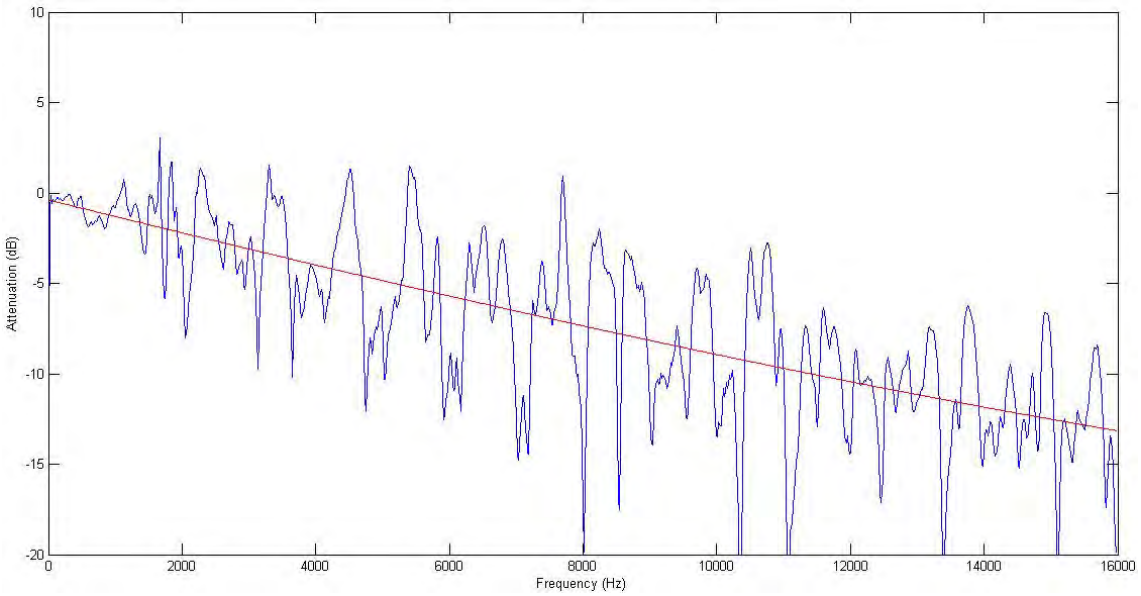

Fig. B. 43: Attenuation for Matt Plus Miniperforated at a distance of 15 cm. 30 degrees

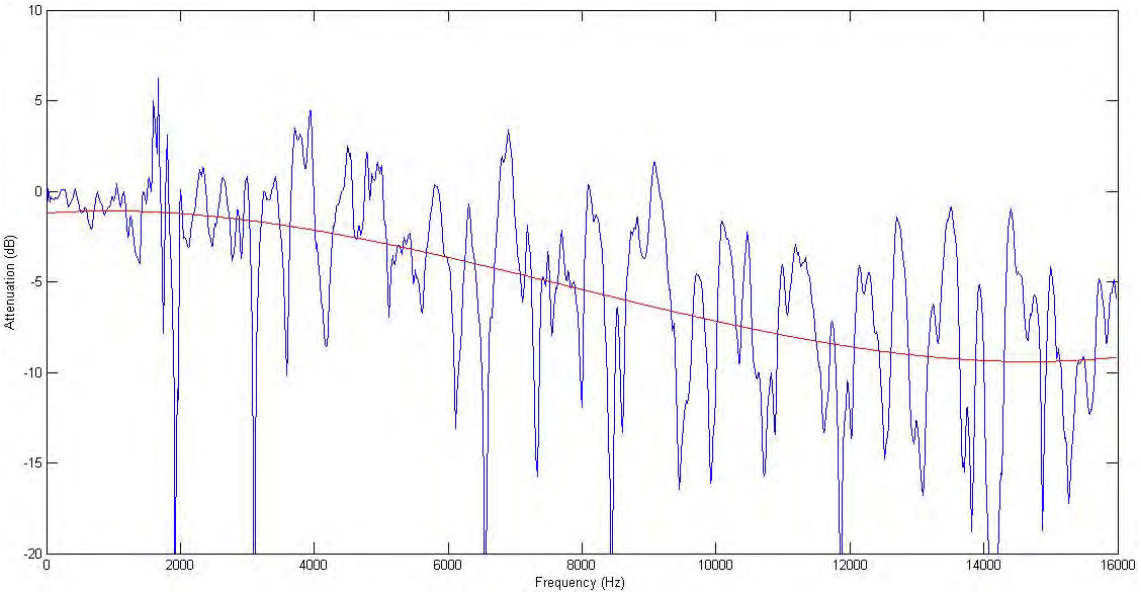

Fig. B. 44: Attenuation for Matt Plus Miniperforated at a distance of 15 cm. 45 degrees

Attenuation for screen Matt Plus Miniperforated at a distance of 30 cm

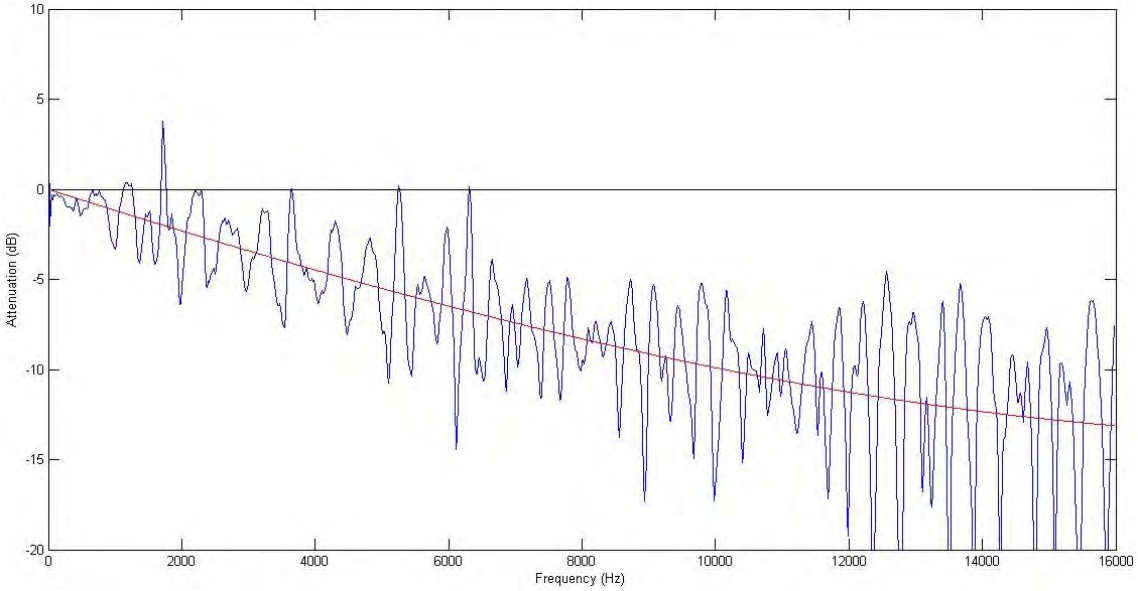

Fig. B. 45: Attenuation for Matt Plus Miniperforated at a distance of 30 cm. 0 degrees

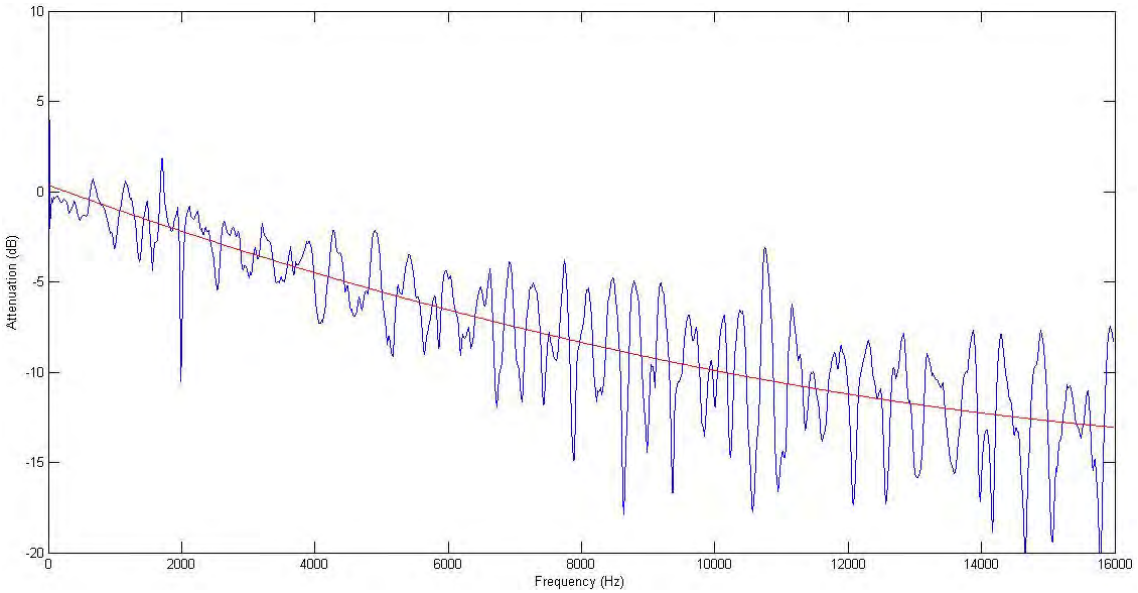

Fig. B. 46: Attenuation for Matt Plus Miniperforated at a distance of 30 cm. 15 degrees

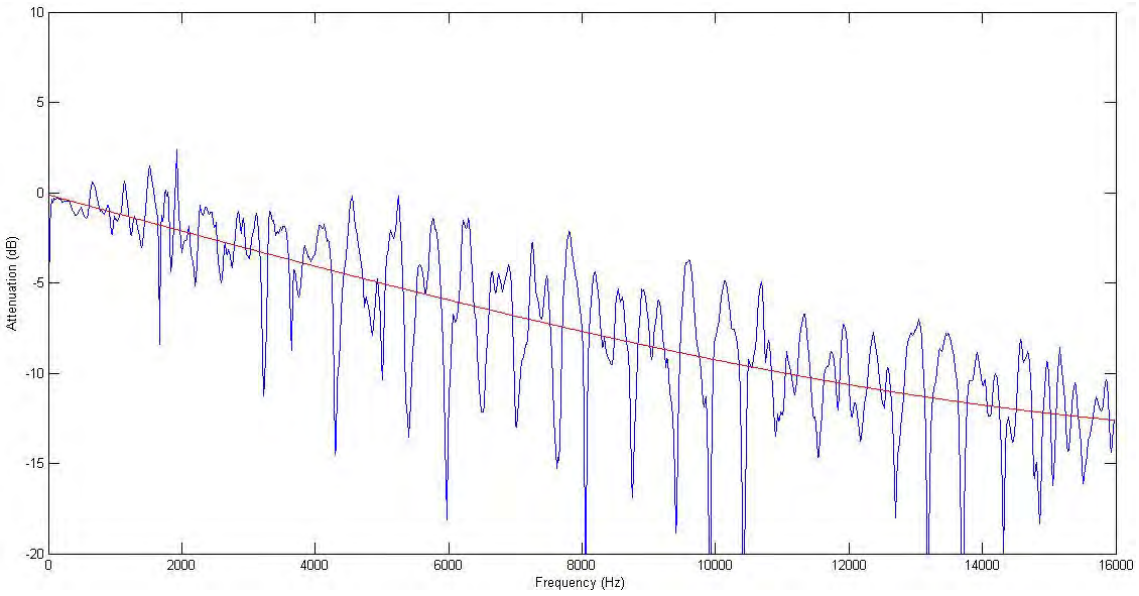

Fig. B. 47: Attenuation for Matt Plus Miniperforated at a distance of 30 cm. 30 degrees

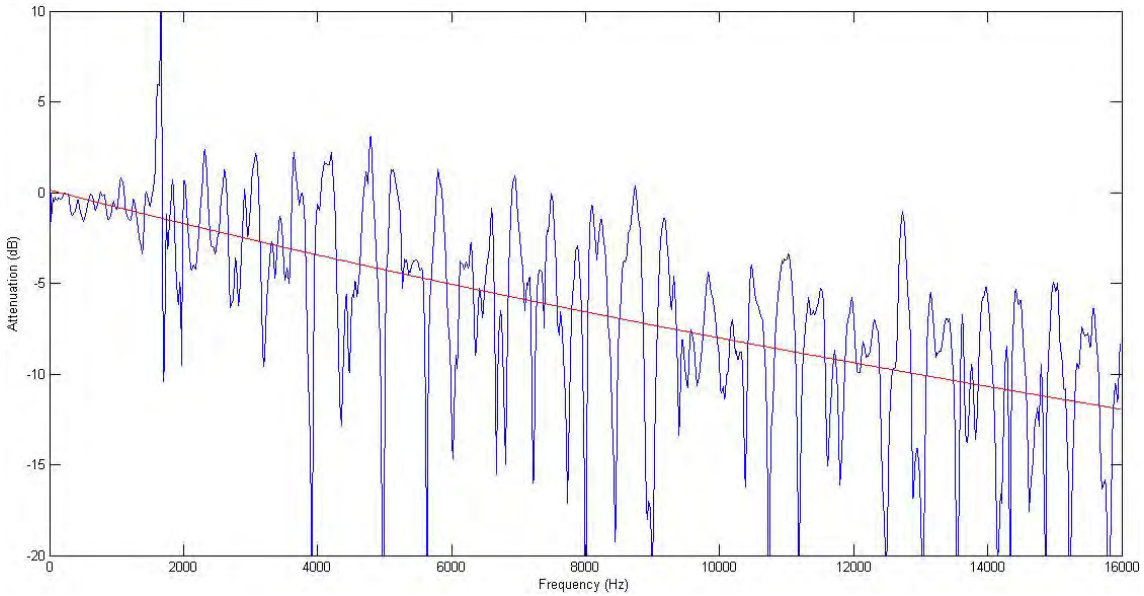

Fig. B. 48: Attenuation for Matt Plus Miniperforated at a distance of 30 cm. 45 degrees

Attenuation for screen Matt Plus Miniperforated at a distance of 45 cm

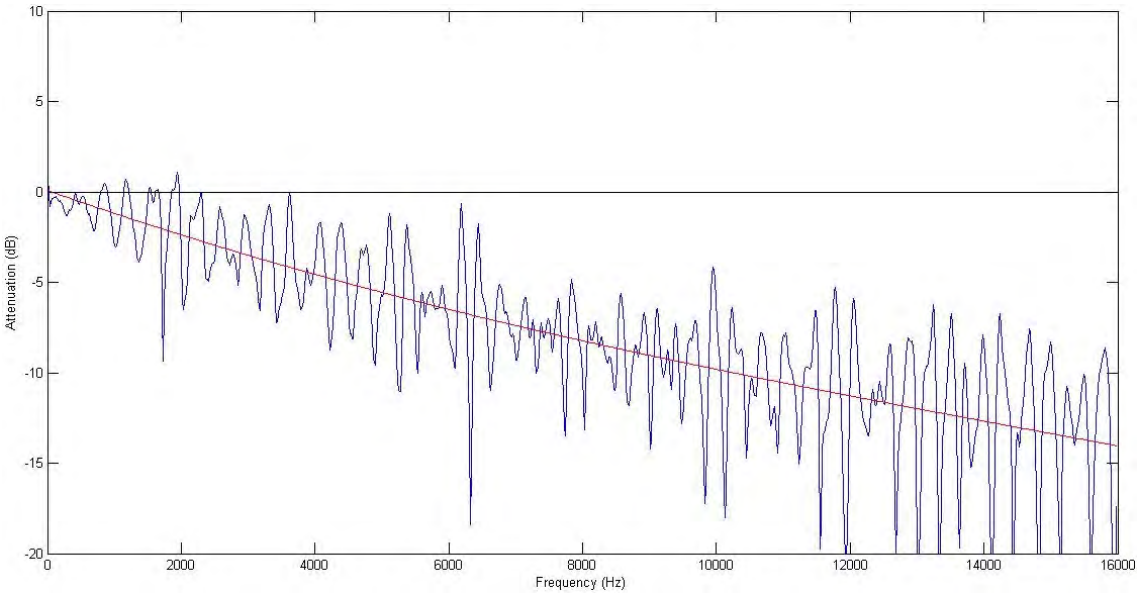

Fig. B. 49: Attenuation for Matt Plus Miniperforated at a distance of 45 cm. 0 degrees

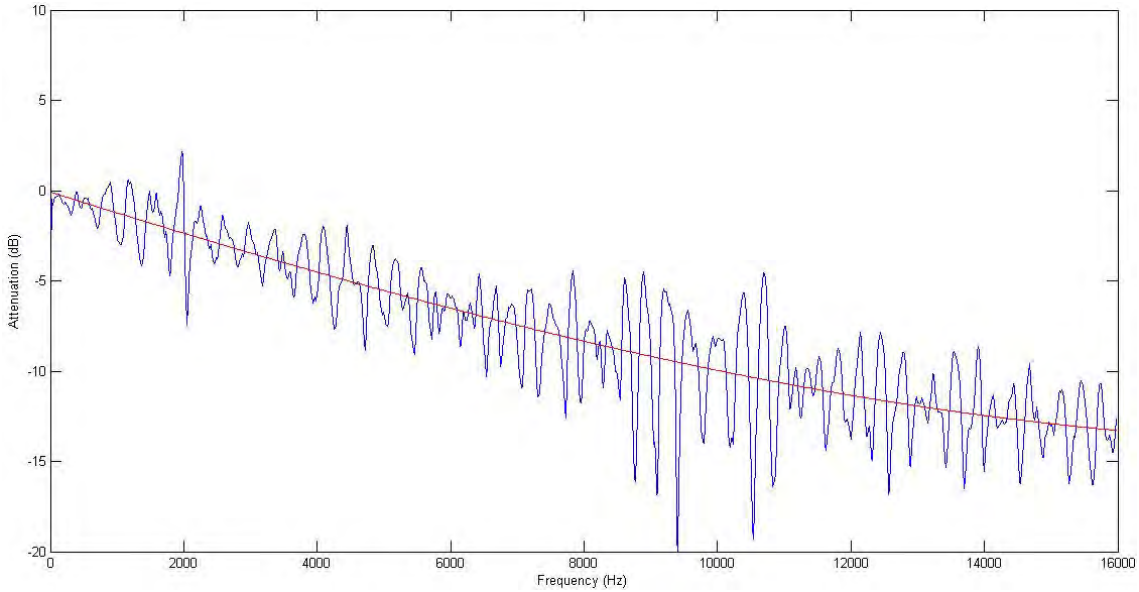

Fig. B. 50: Attenuation for Matt Plus Miniperforated at a distance of 45 cm. 15 degrees

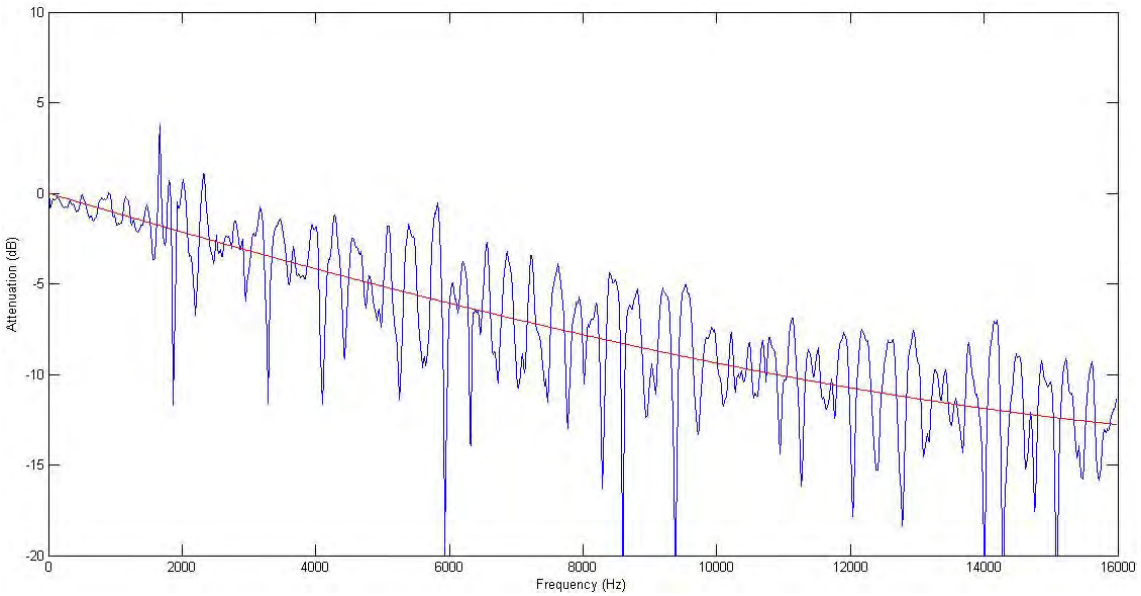

Fig. B. 51: Attenuation for Matt Plus Miniperforated at a distance of 45 cm. 30 degrees

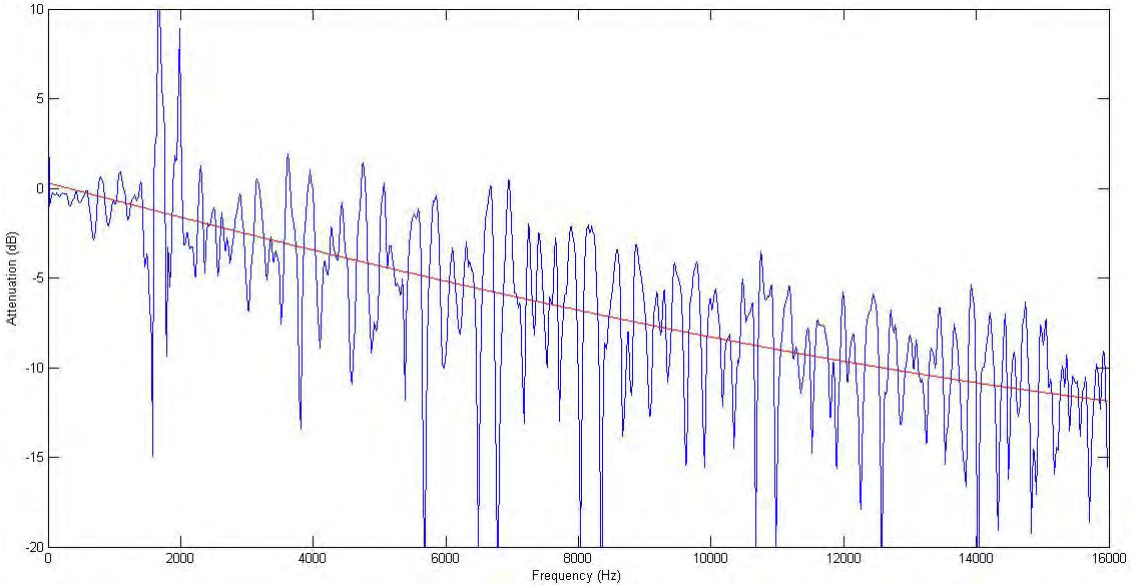

Fig. B. 52: Attenuation for Matt Plus Miniperforated at a distance of 45 cm. 45 degrees

Attenuation for screen Matt Plus Miniperforated at a distance of 60 cm

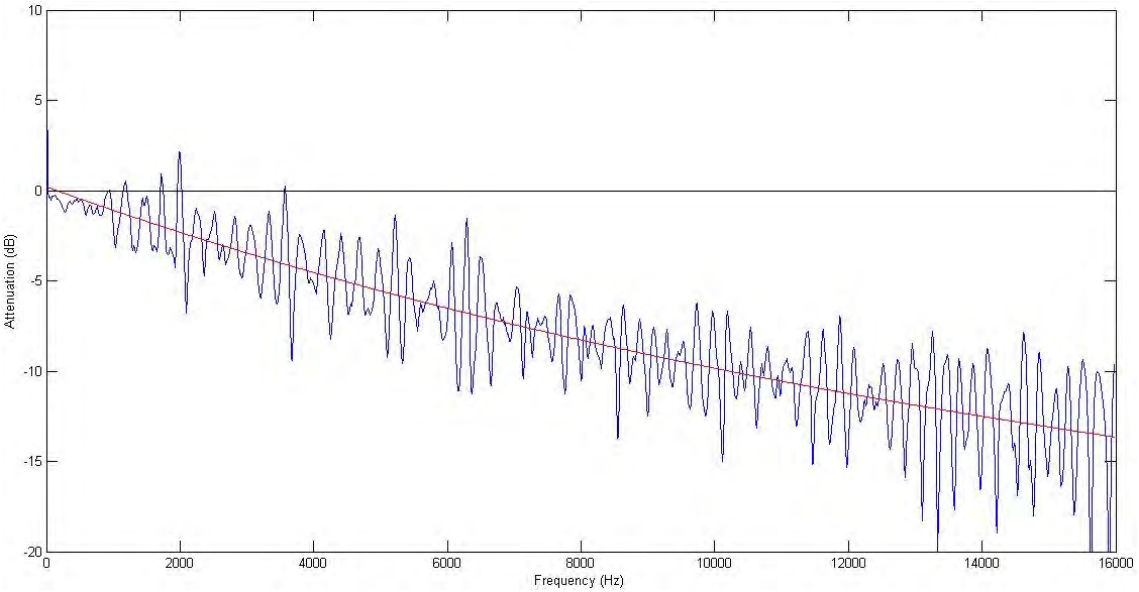

Fig. B. 53: Attenuation for Matt Plus Miniperforated at a distance of 60 cm. 0 degrees

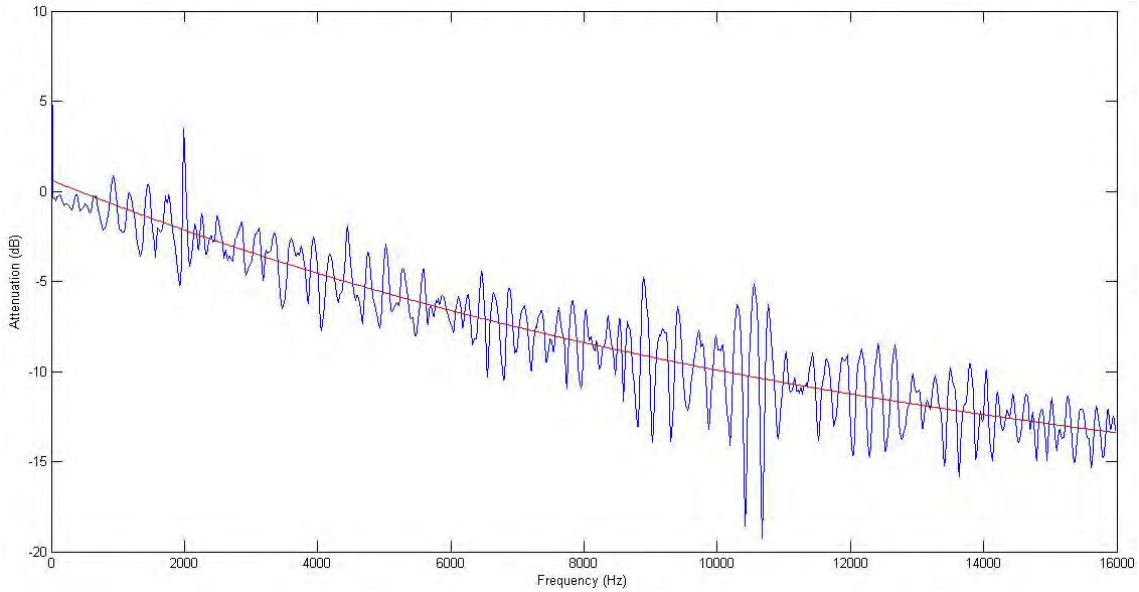

Fig. B. 54: Attenuation for Matt Plus Miniperforated at a distance of 60 cm. 15 degrees

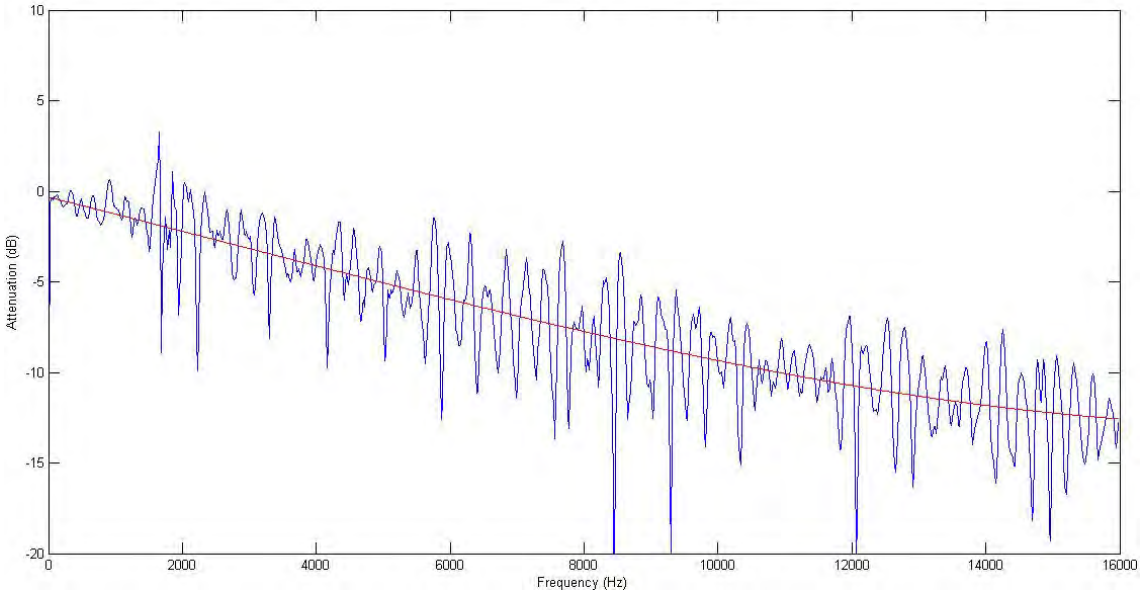

Fig. B. 55: Attenuation for Matt Plus Miniperforated at a distance of 60 cm. 30 degrees

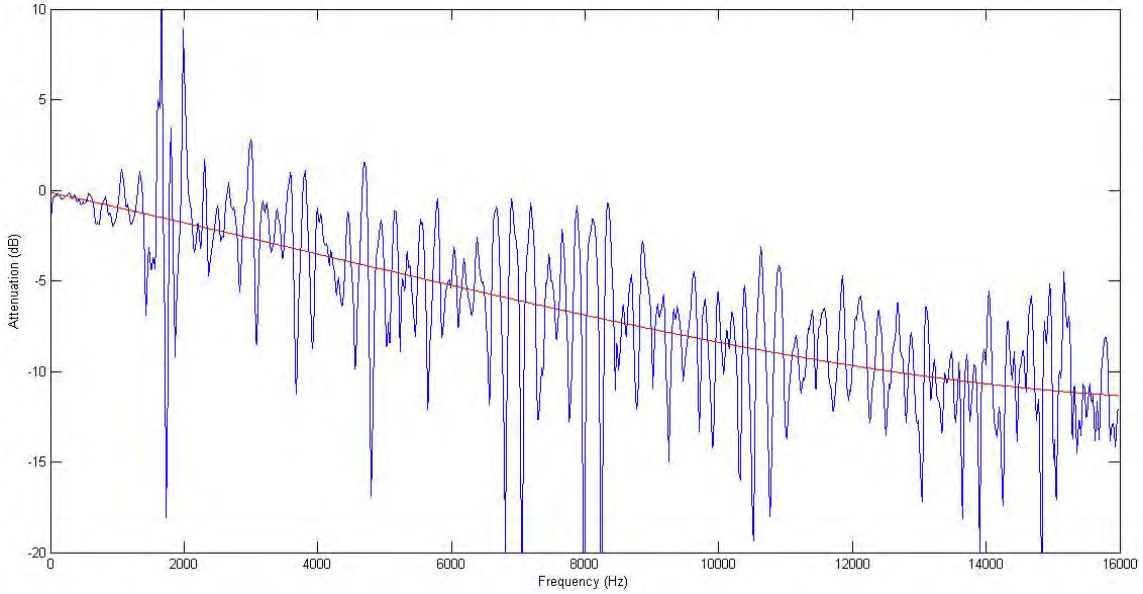

Fig. B. 56: Attenuation for Matt Plus Miniperforated at a distance of 60 cm. 45 degrees

Attenuation for screen Matt Plus Miniperforated with screen angled 10 deg

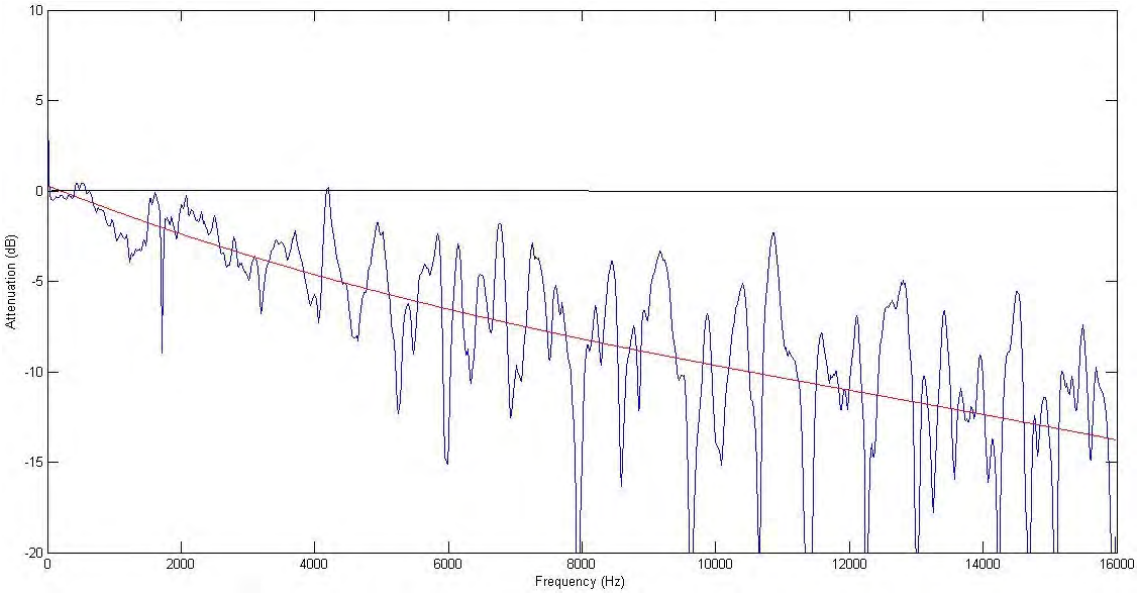

Fig. B. 57: Attenuation for Matt Plus Miniperforated with screen angled 10 degrees. Mic position 0 deg

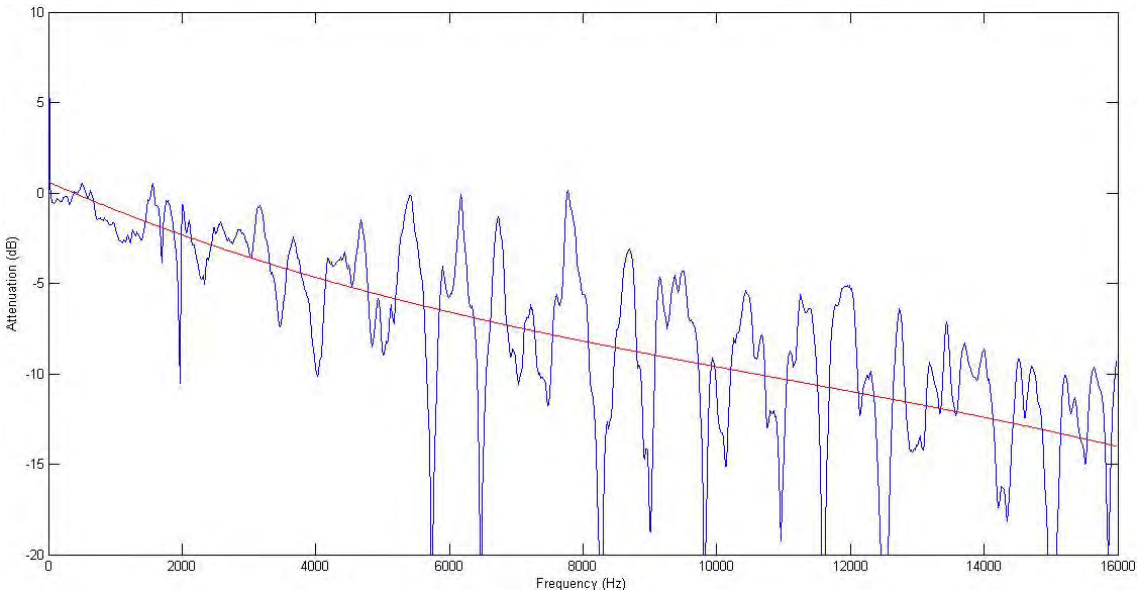

Fig. B. 58: Attenuation for Matt Plus Miniperforated with screen angled 10 degrees. Mic position 15 deg

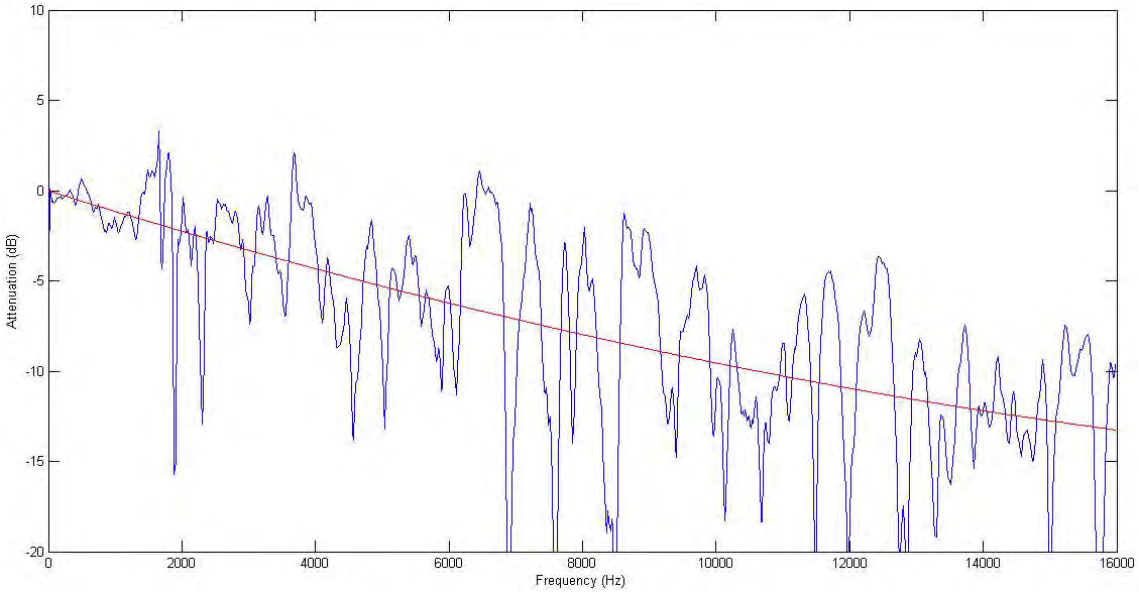

Fig. B. 59: Attenuation for Matt Plus Miniperforated with screen angled 10 degrees. Mic position 30 deg

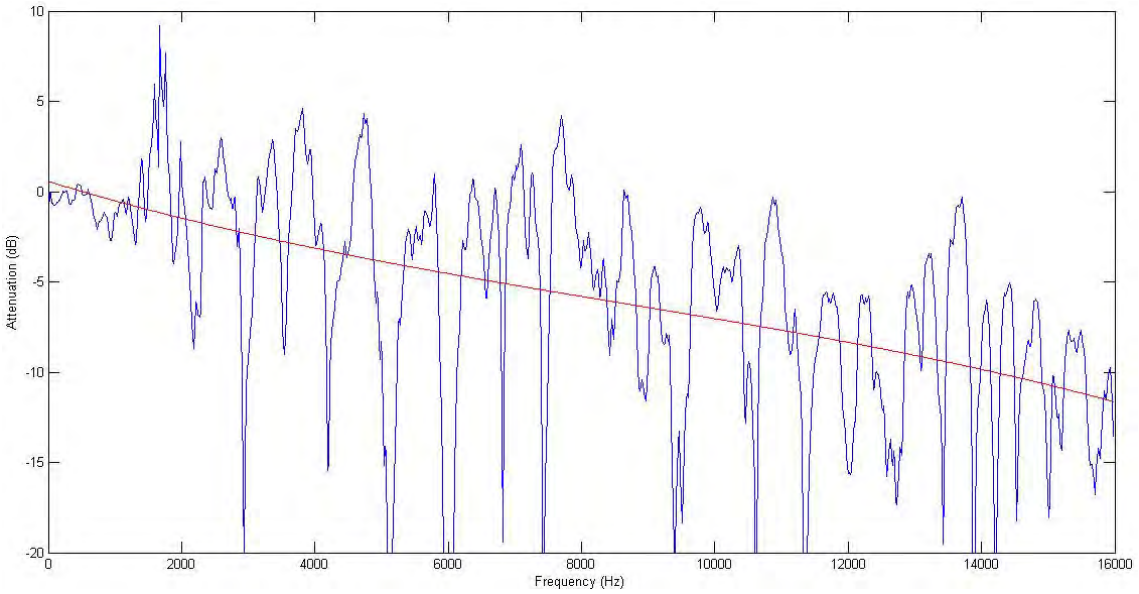

Fig. B. 60: Attenuation for Matt Plus Miniperforated with screen angled 10 degrees. Mic position 45 deg

Attenuation for screen Matt Plus Miniperforated with screen angled 25 deg

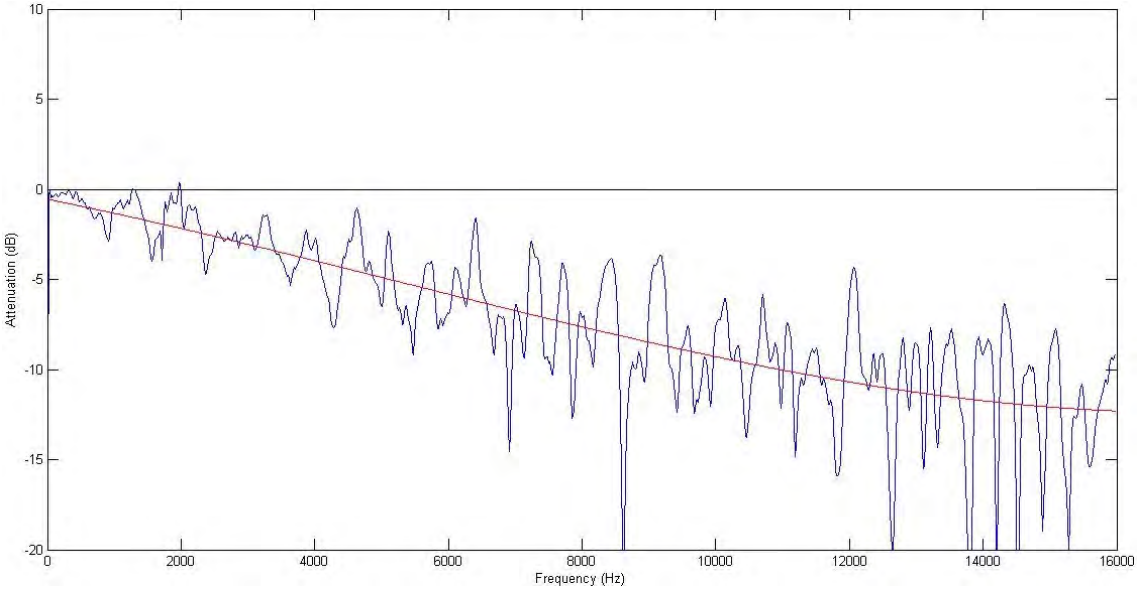

Fig. B. 61: Attenuation for Matt Plus Miniperforated with screen angled 25 degrees. Mic position 0 deg

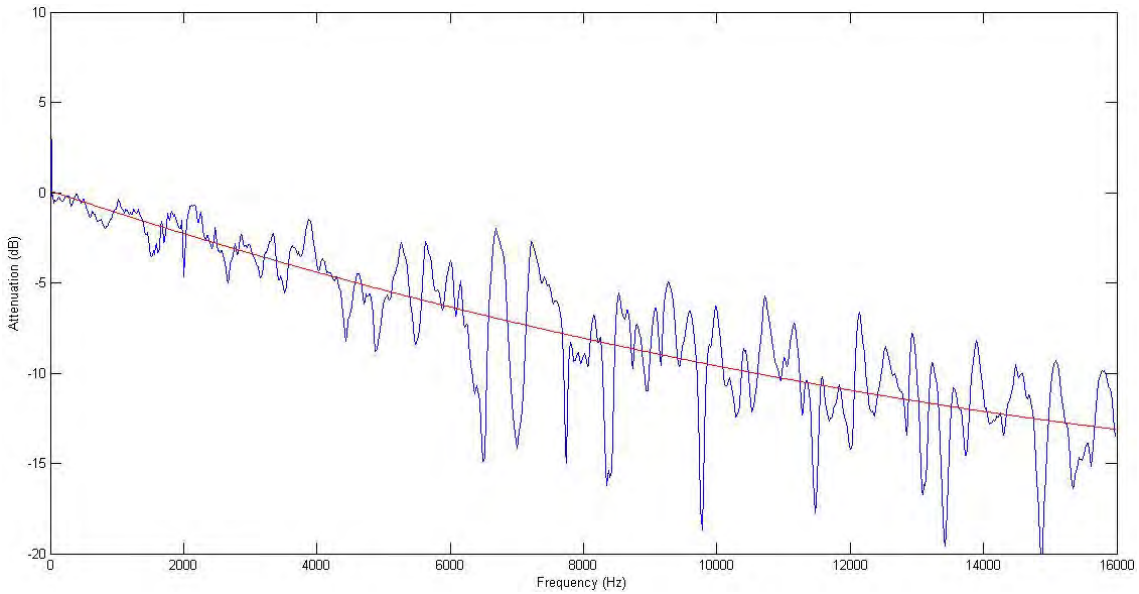

Fig. B. 62: Attenuation for Matt Plus Miniperforated with screen angled 25 degrees. Mic position 15 deg

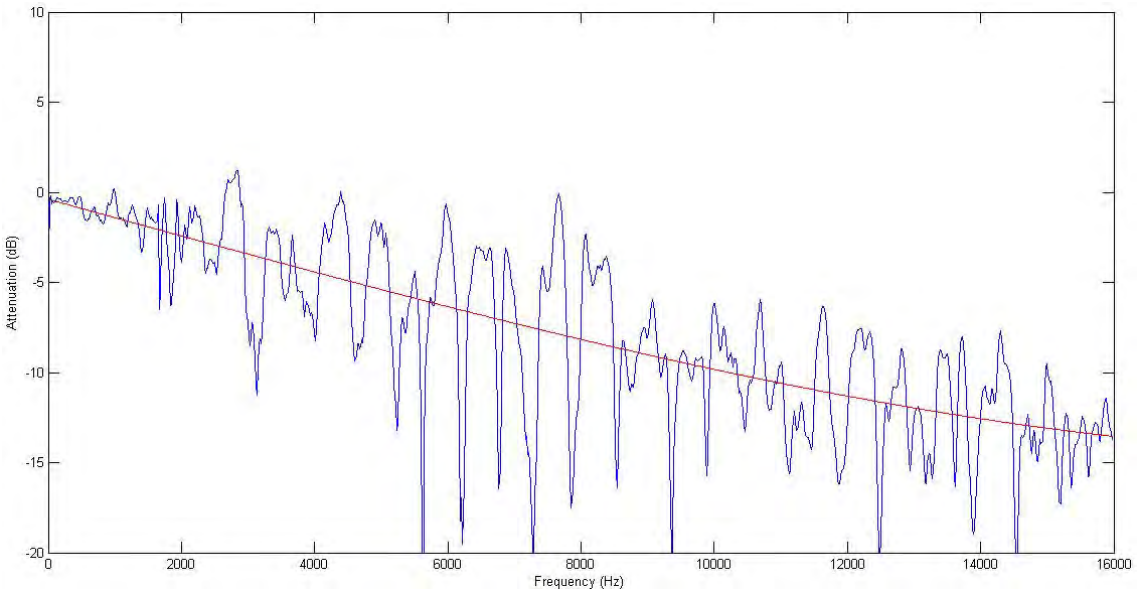

Fig. B. 63: Attenuation for Matt Plus Miniperforated with screen angled 25 degrees. Mic position 30 deg

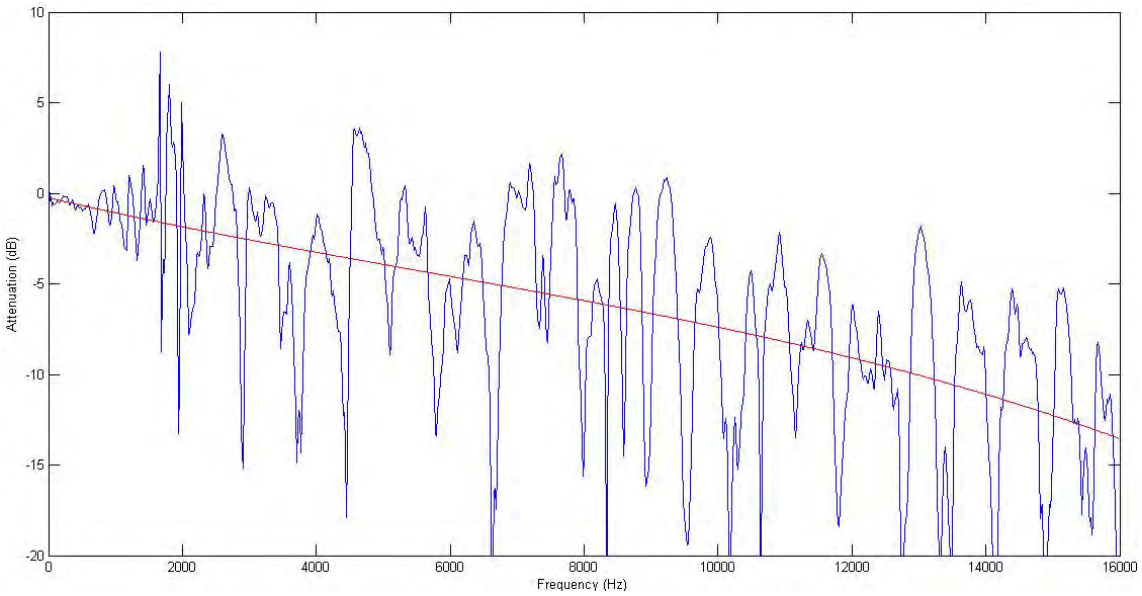

Fig. B. 64: Attenuation for Matt Plus Miniperforated with screen angled 25 degrees. Mic position 45 deg

B. 3. ClearPix 2 White 1.0

Attenuation for screen ClearPix 2 White 1.0 at a distance of 2 cm

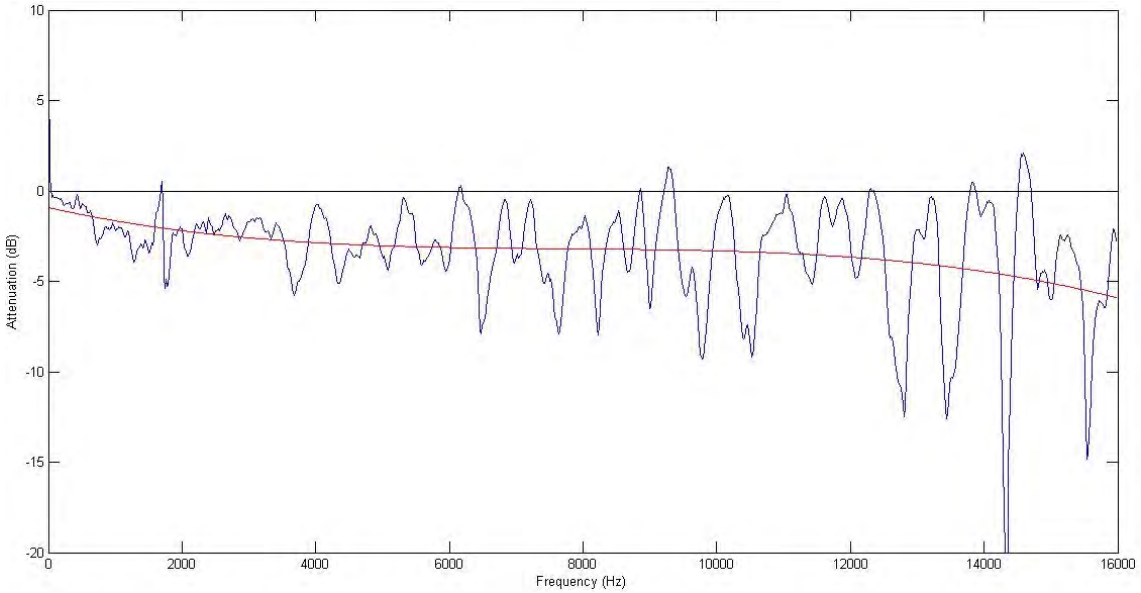

Fig. B. 65: Attenuation for ClearPix 2 White 1.0 at a distance of 2 cm. 0 degrees

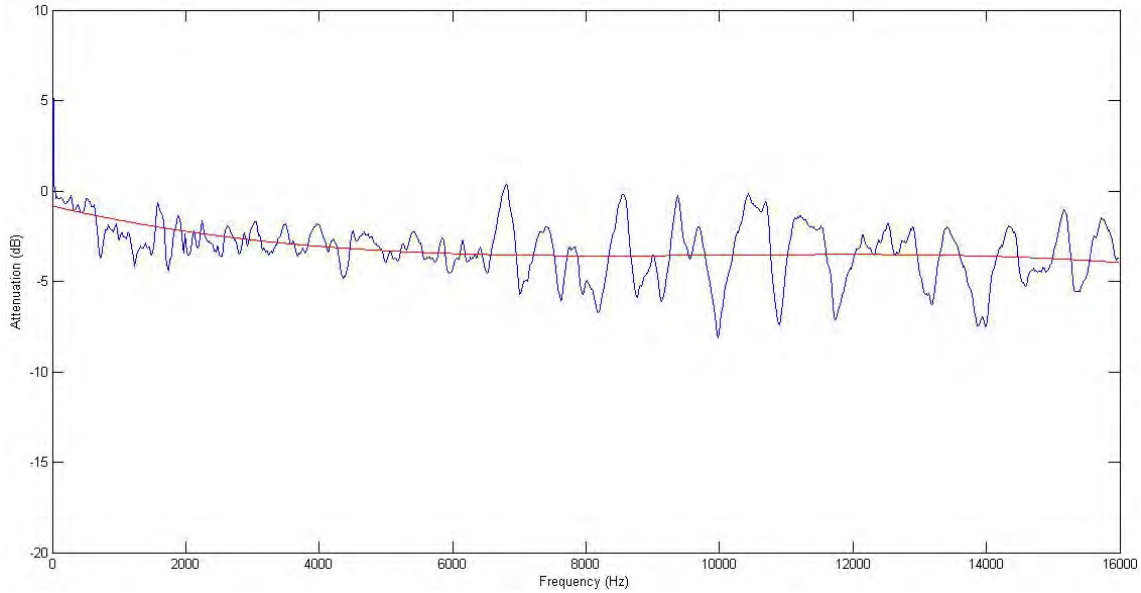

Fig. B. 66: Attenuation for ClearPix 2 White 1.0 at a distance of 2 cm. 15 degrees

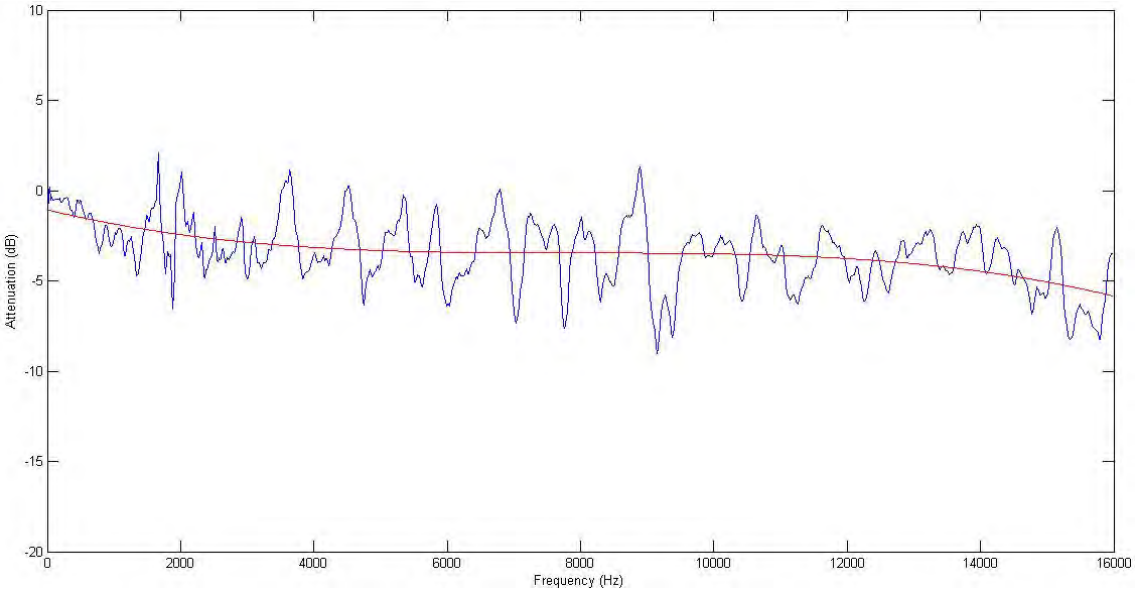

Fig. B. 67: Attenuation for ClearPix 2 White 1.0 at a distance of 2 cm. 30 degrees

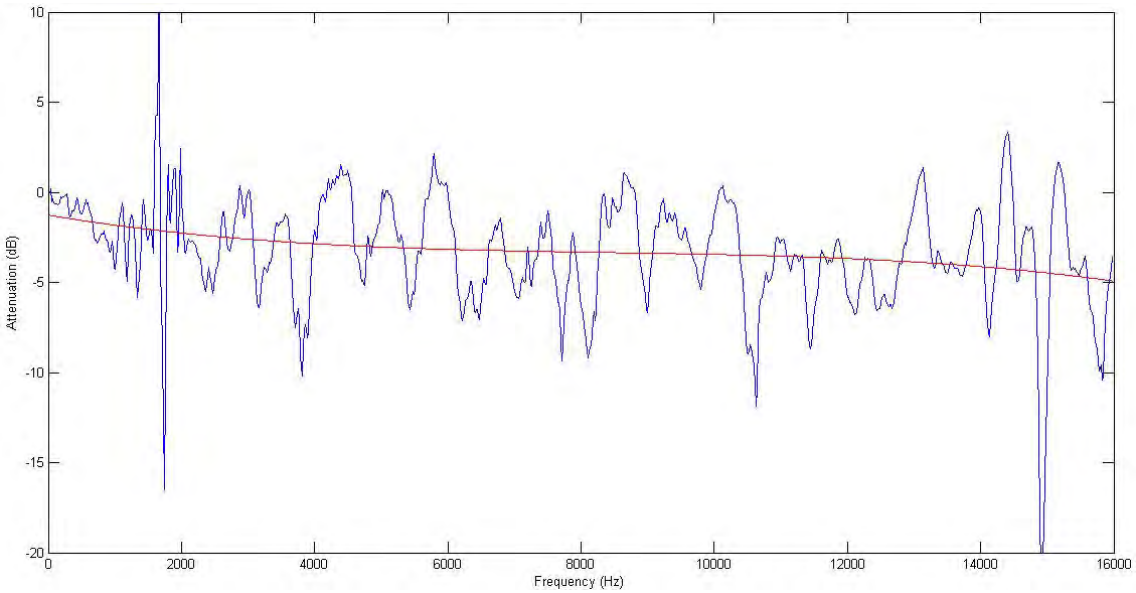

Fig. B. 68: Attenuation for ClearPix 2 White 1.0 at a distance of 2 cm. 45 degrees

Attenuation for screen ClearPix 2 White 1.0 at a distance of 7 cm

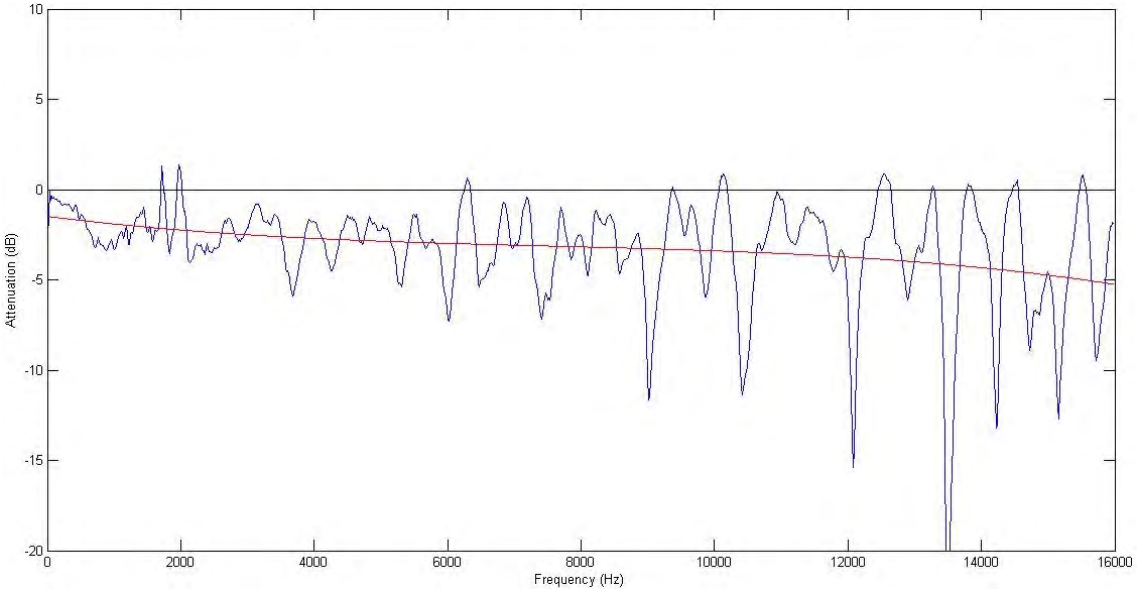

Fig. B. 69: Attenuation for ClearPix 2 White 1.0 at a distance of 7 cm. 0 degrees

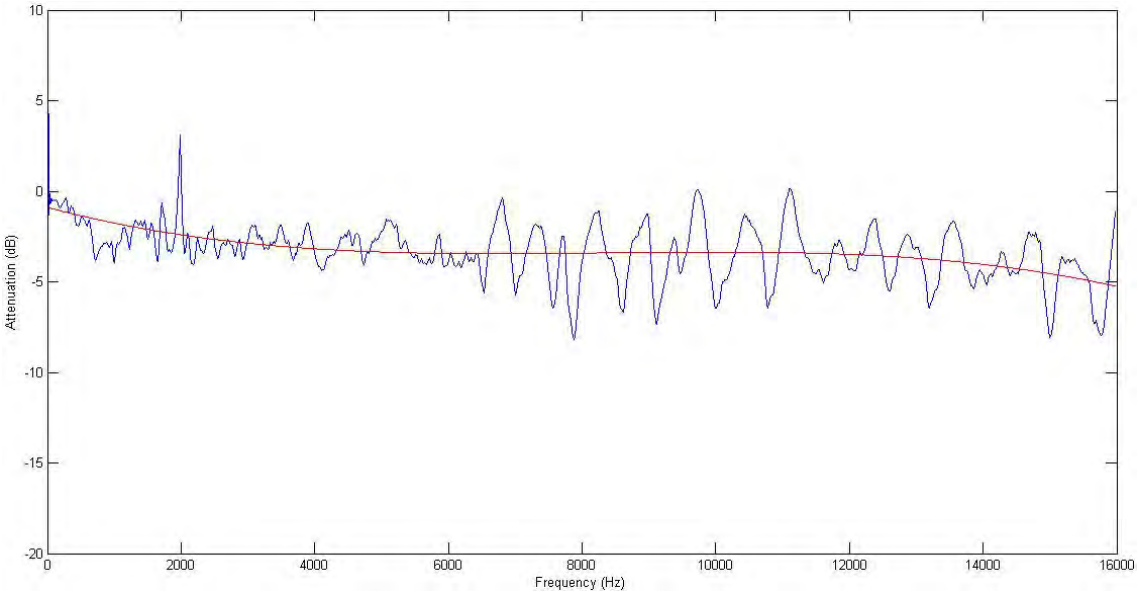

Fig. B. 70: Attenuation for ClearPix 2 White 1.0 at a distance of 7 cm. 15 degrees

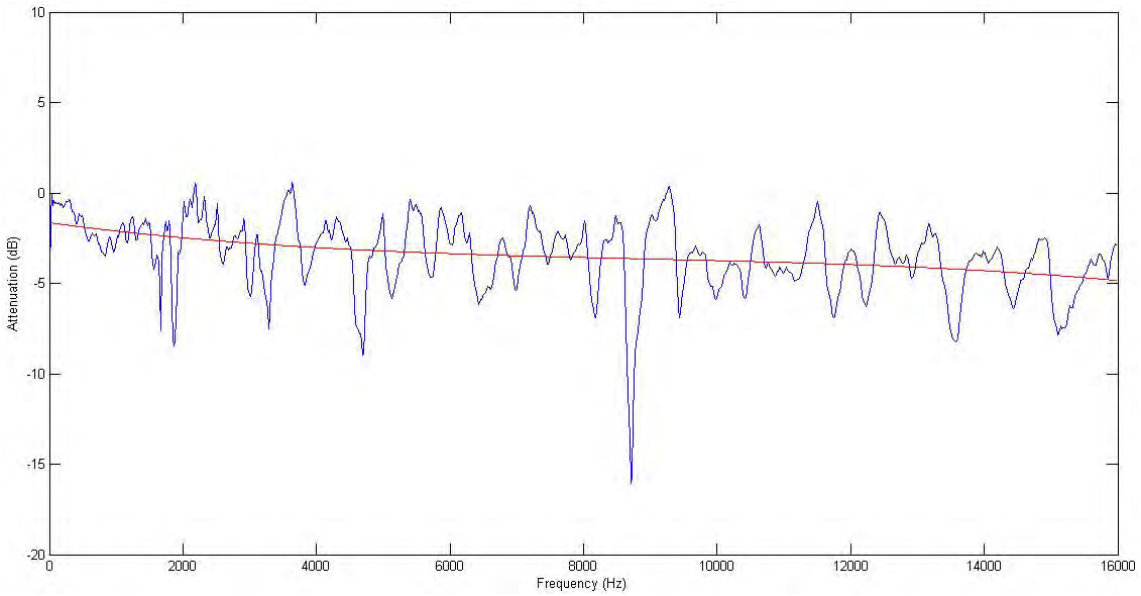

Fig. B. 71: Attenuation for ClearPix 2 White 1.0 at a distance of 7 cm. 30 degrees

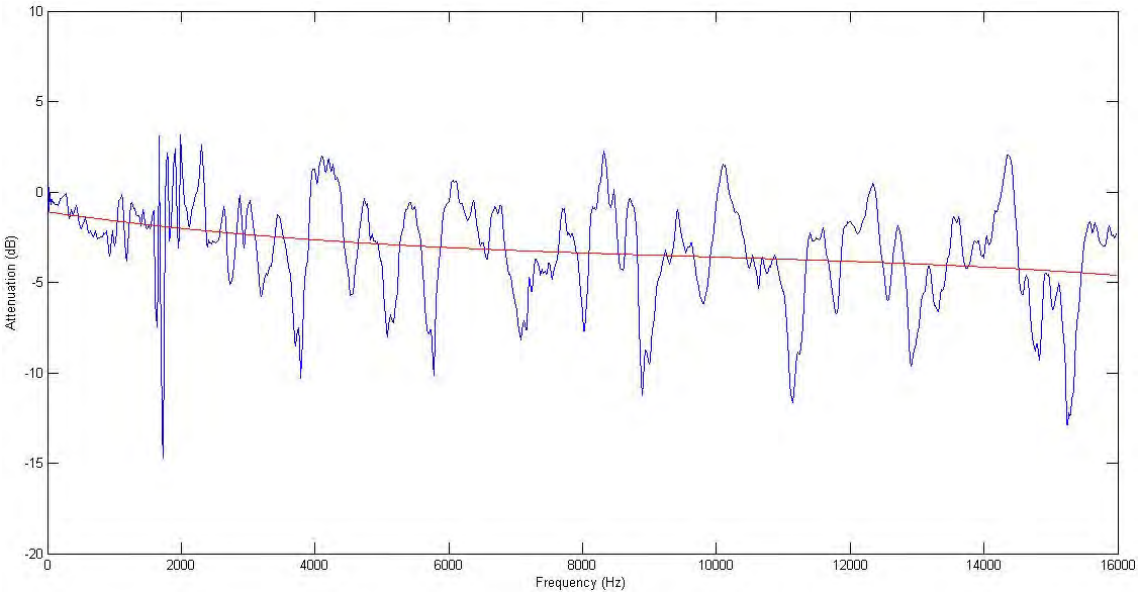

Fig. B. 72: Attenuation for ClearPix 2 White 1.0 at a distance of 7 cm. 45 degrees

Attenuation for screen ClearPix 2 White 1.0 at a distance of 15 cm

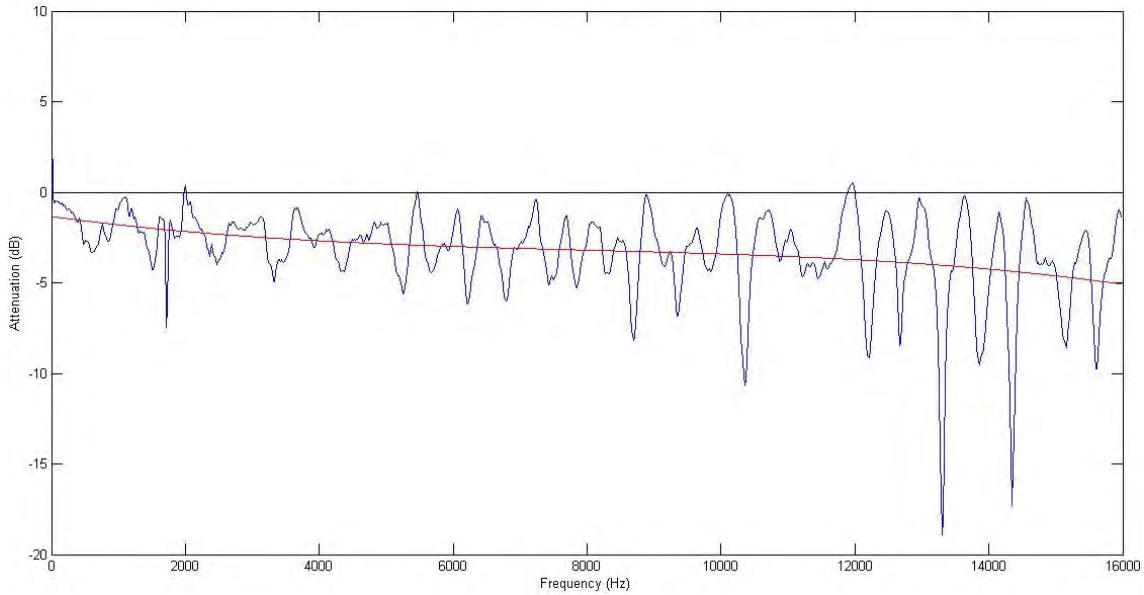

Fig. B. 73: Attenuation for ClearPix 2 White 1.0 at a distance of 15 cm. 0 degrees

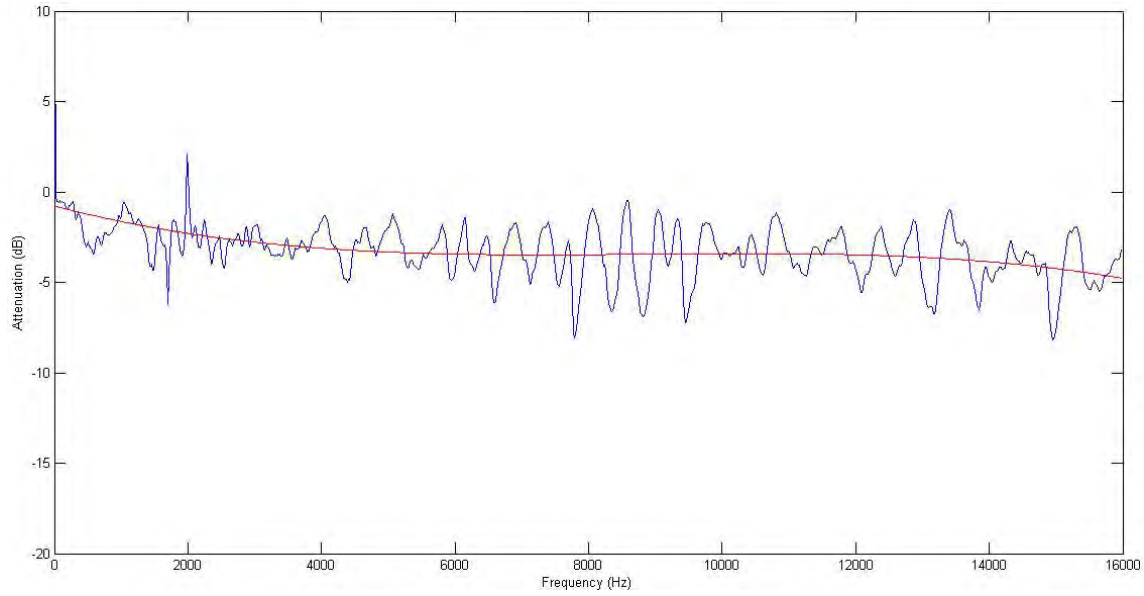

Fig. B. 74: Attenuation for ClearPix 2 White 1.0 at a distance of 15 cm. 15 degrees

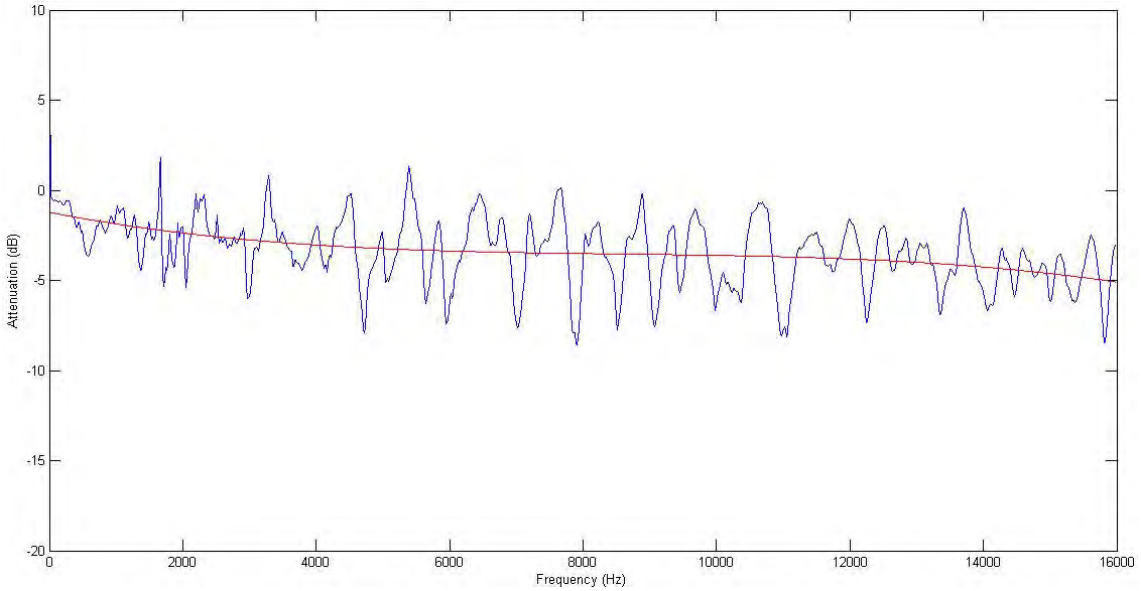

Fig. B. 75: Attenuation for ClearPix 2 White 1.0 at a distance of 15 cm. 30 degrees

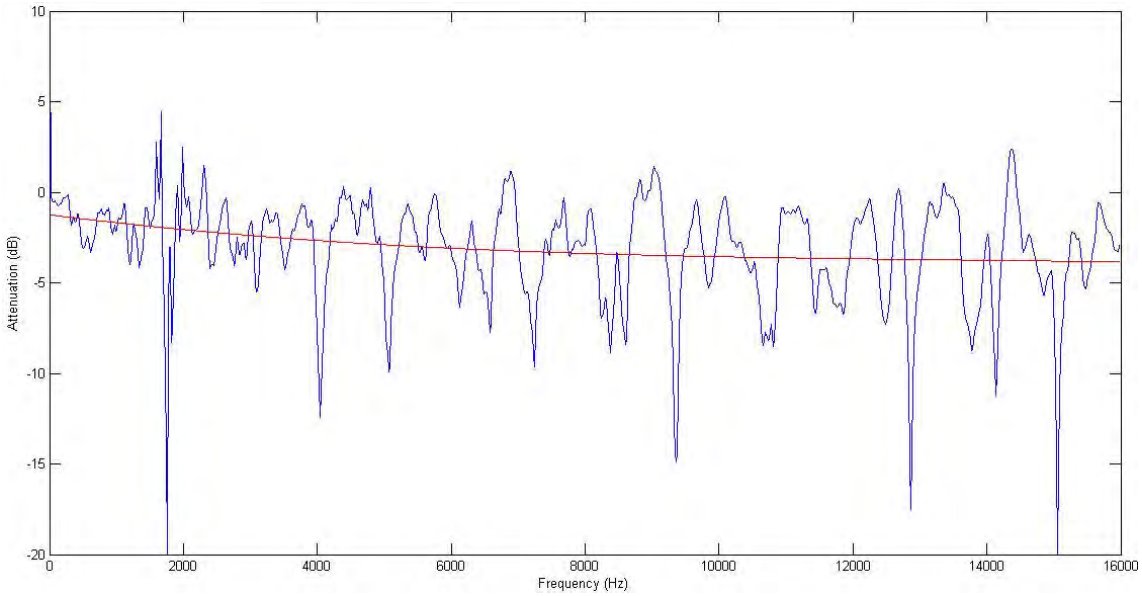

Fig. B. 76: Attenuation for ClearPix 2 White 1.0 at a distance of 15 cm. 45 degrees

Attenuation for screen ClearPix 2 White 1.0 at a distance of 30 cm

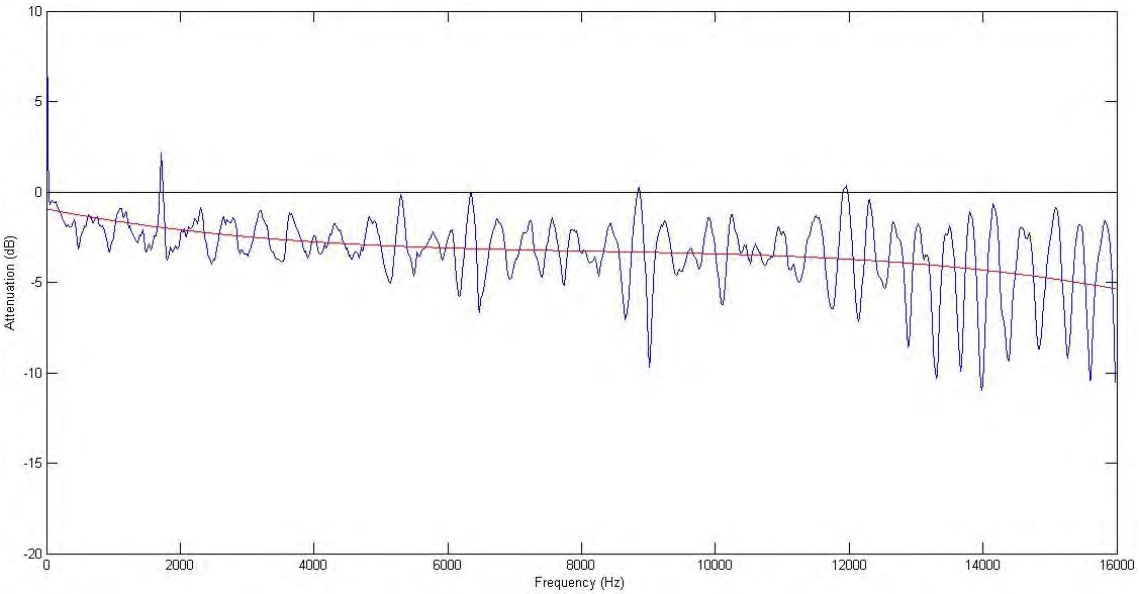

Fig. B. 77: Attenuation for ClearPix 2 White 1.0 at a distance of 30 cm. 0 degrees

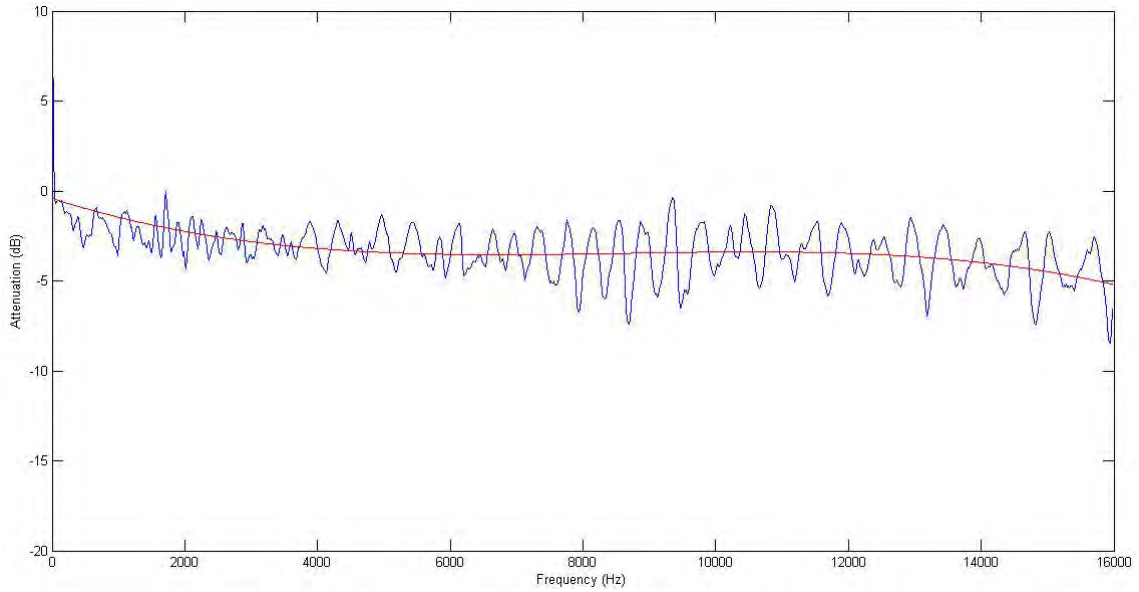

Fig. B. 78: Attenuation for ClearPix 2 White 1.0 at a distance of 30 cm. 15 degrees

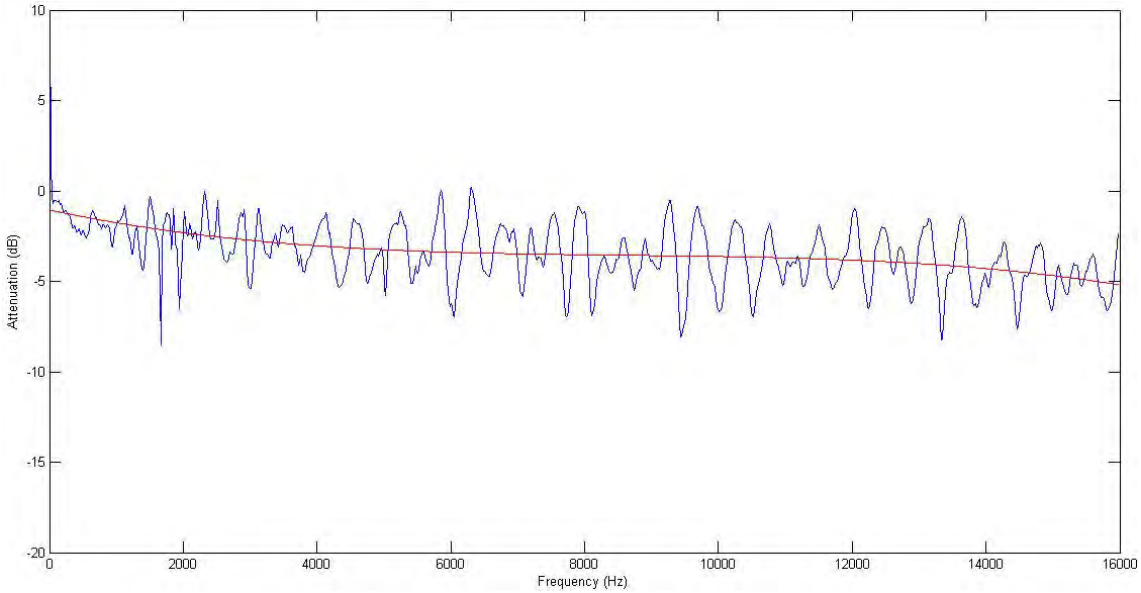

Fig. B. 79: Attenuation for ClearPix 2 White 1.0 at a distance of 30 cm. 30 degrees

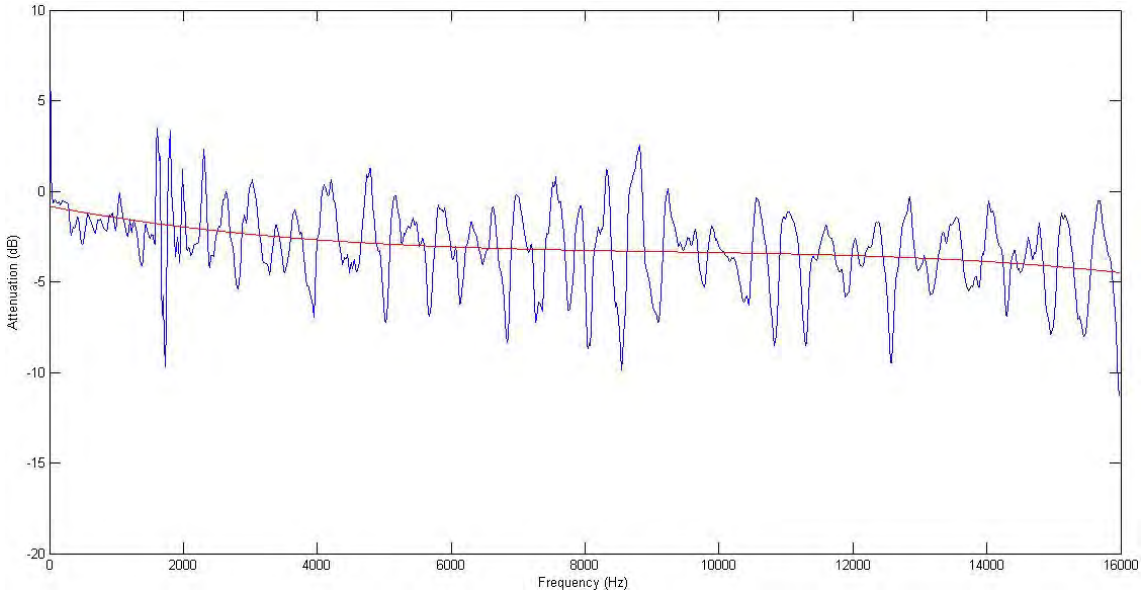

Fig. B. 80: Attenuation for ClearPix 2 White 1.0 at a distance of 30 cm. 45 degrees

Attenuation for screen ClearPix 2 White 1.0 at a distance of 45 cm

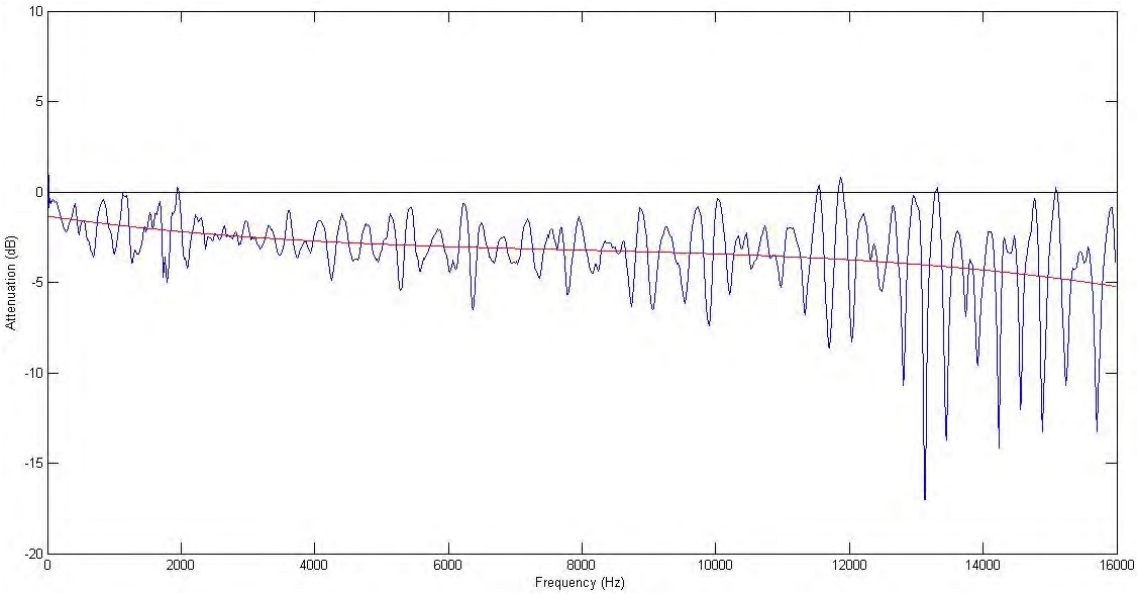

Fig. B. 81: Attenuation for ClearPix 2 White 1.0 at a distance of 45 cm. 0 degrees

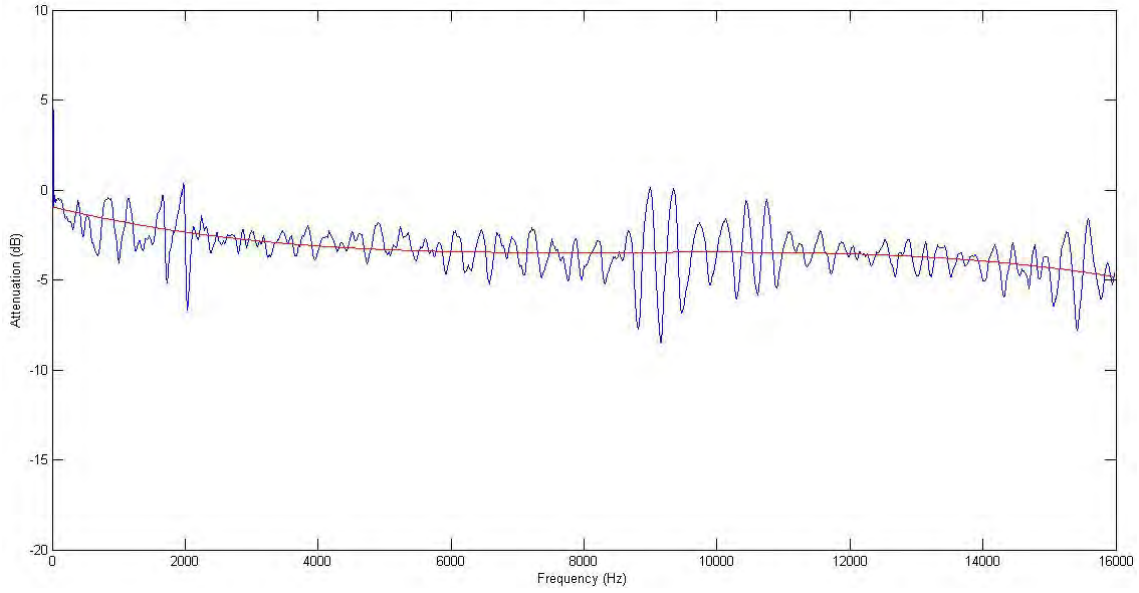

Fig. B. 82: Attenuation for ClearPix 2 White 1.0 at a distance of 45 cm. 15 degrees

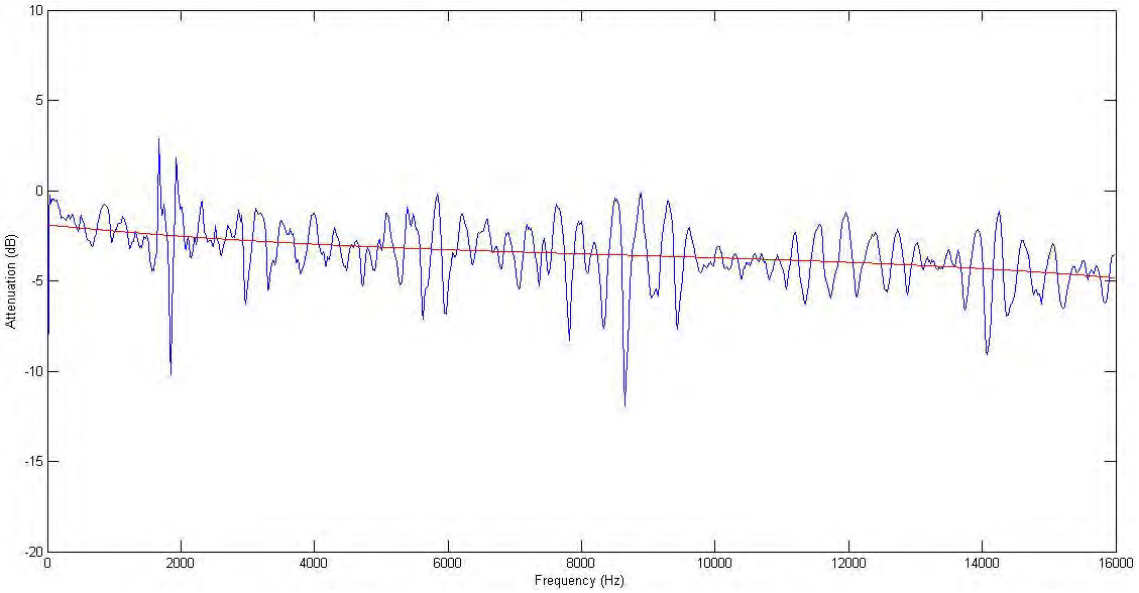

Fig. B. 83: Attenuation for ClearPix 2 White 1.0 at a distance of 45 cm. 30 degrees

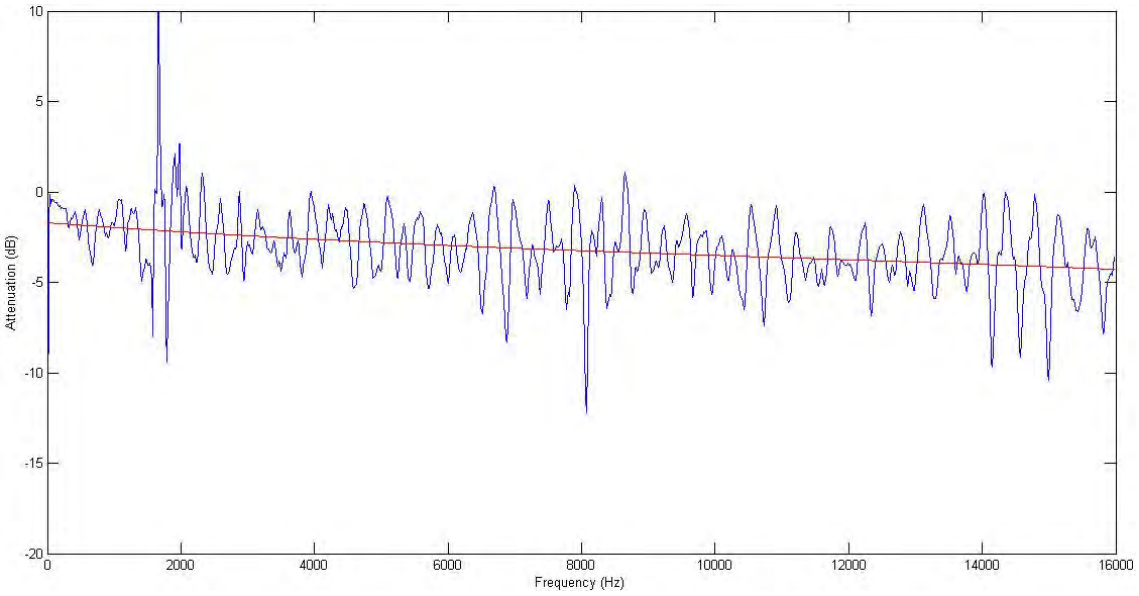

Fig. B. 84: Attenuation for ClearPix 2 White 1.0 at a distance of 45 cm. 30 degrees

Attenuation for screen ClearPix 2 White 1.0 at a distance of 60 cm

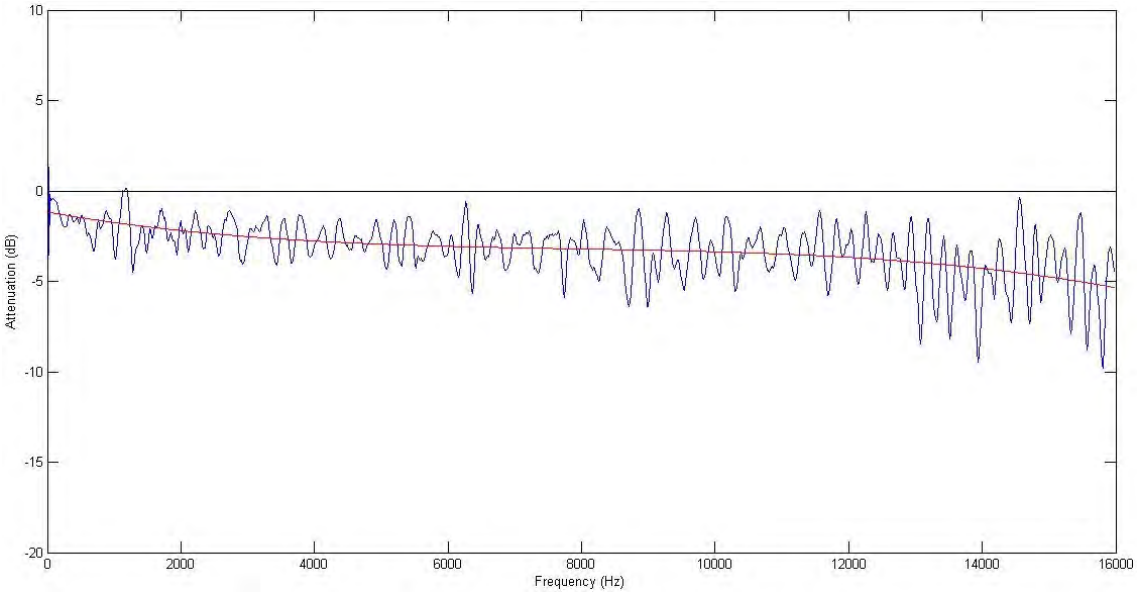

Fig. B. 85: Attenuation for ClearPix 2 White 1.0 at a distance of 60 cm. 0 degrees

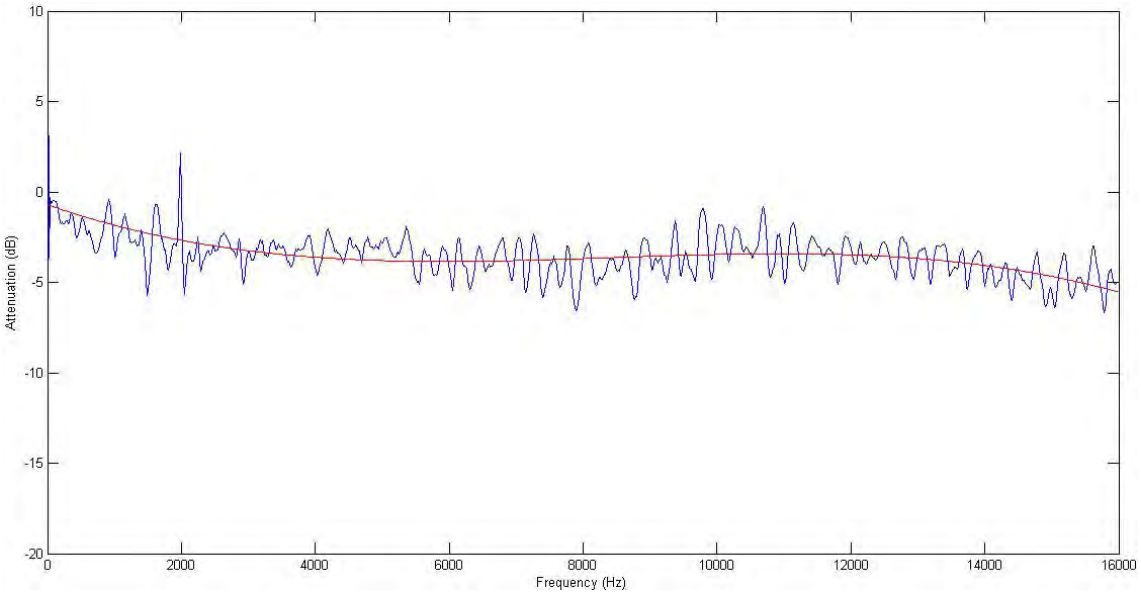

Fig. B. 86: Attenuation for ClearPix 2 White 1.0 at a distance of 60 cm. 15 degrees

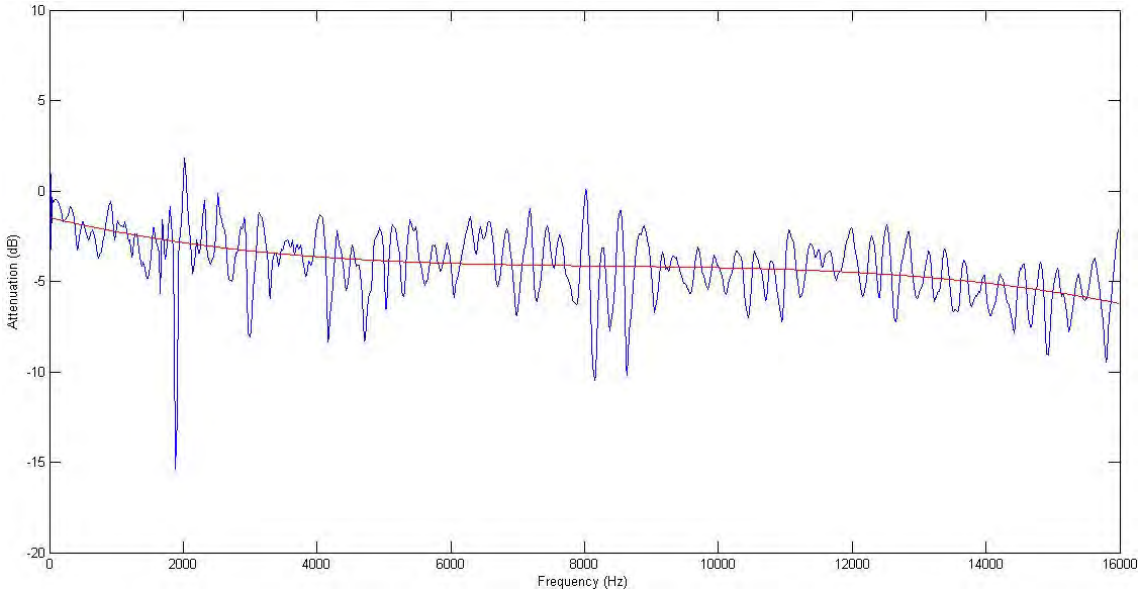

Fig. B. 87: Attenuation for ClearPix 2 White 1.0 at a distance of 60 cm. 30 degrees

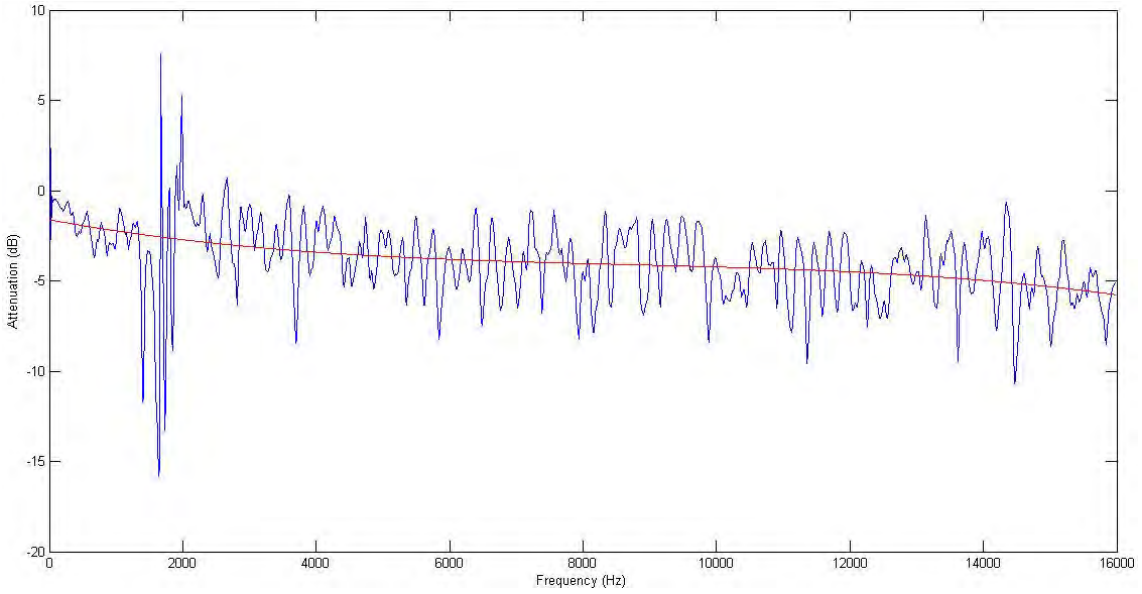

Fig. B. 88: Attenuation for ClearPix 2 White 1.0 at a distance of 60 cm. 45 degrees

Attenuation for screen ClearPix 2 White 1.0 with screen angled 10 deg

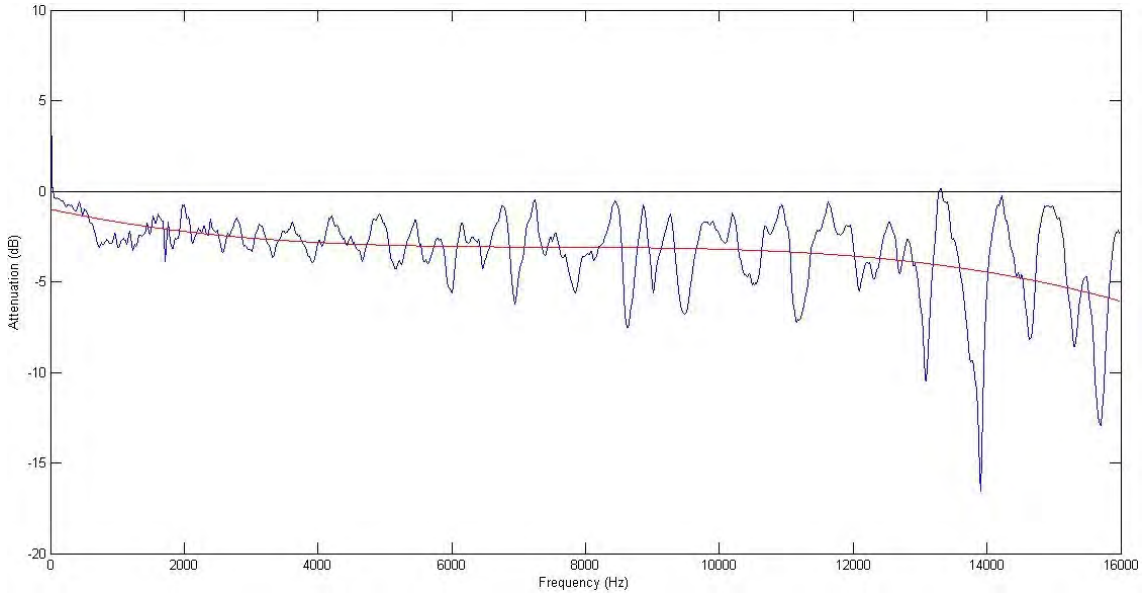

Fig. B. 89: Attenuation for ClearPix 2 White 1.0 with screen angled 10 degrees. Mic position 0 deg

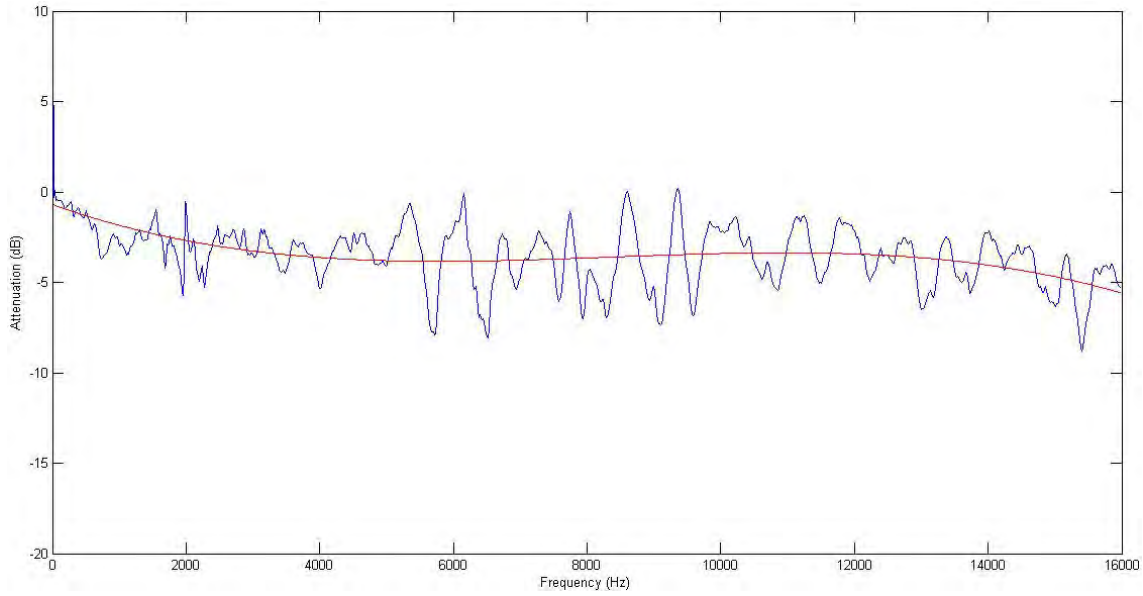

Fig. B. 90: Attenuation for ClearPix 2 White 1.0 with screen angled 10 degrees. Mic position 15 deg

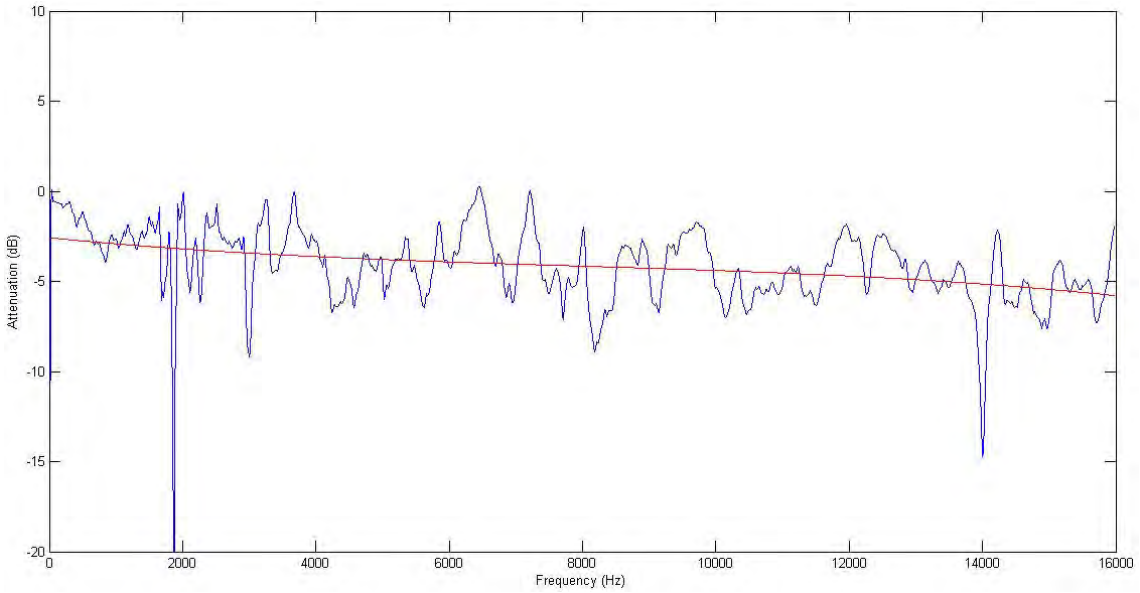

Fig. B. 91: Attenuation for ClearPix 2 White 1.0 with screen angled 10 degrees. Mic position 30 deg

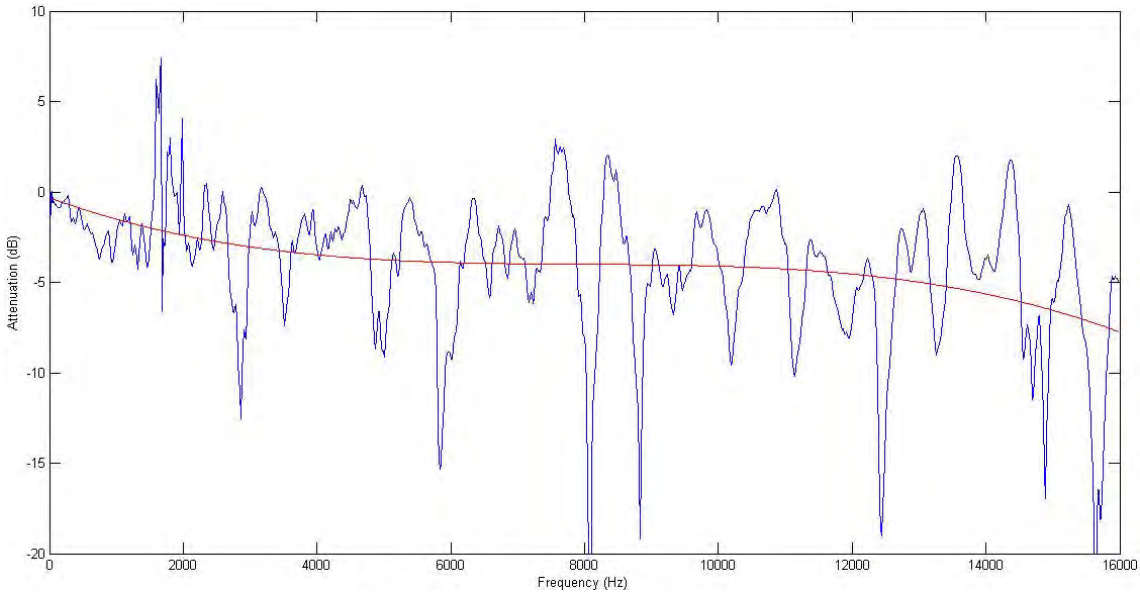

Fig. B. 92: Attenuation for ClearPix 2 White 1.0 with screen angled 10 degrees. Mic position 45 deg

Attenuation for screen ClearPix 2 White 1.0 with screen angled 25 deg

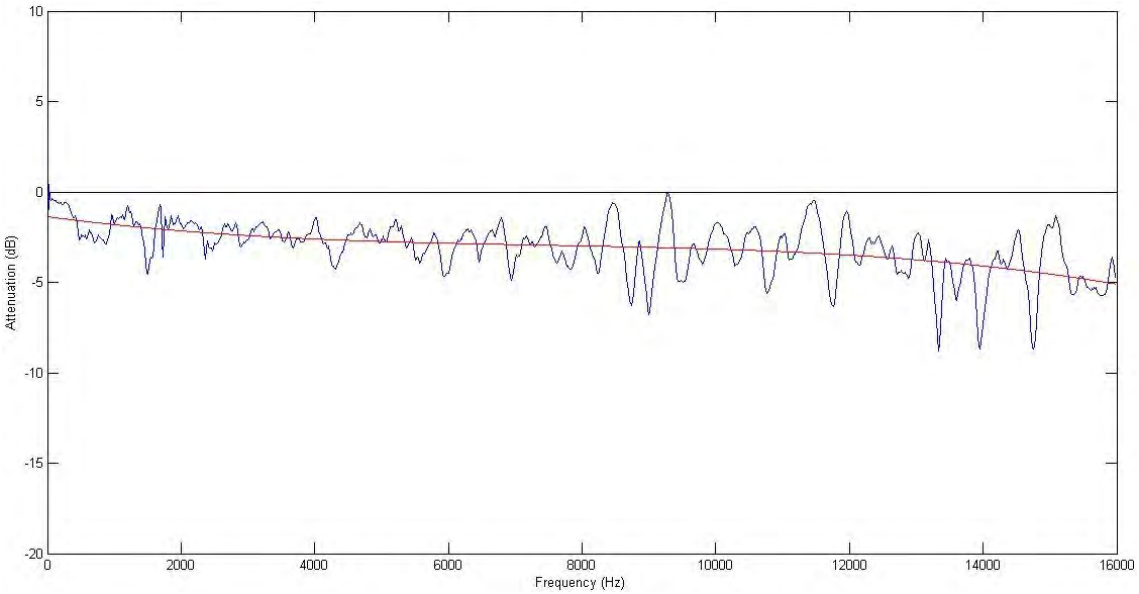

Fig. B. 93: Attenuation for ClearPix 2 White 1.0 with screen angled 25 degrees. Mic position 0 deg

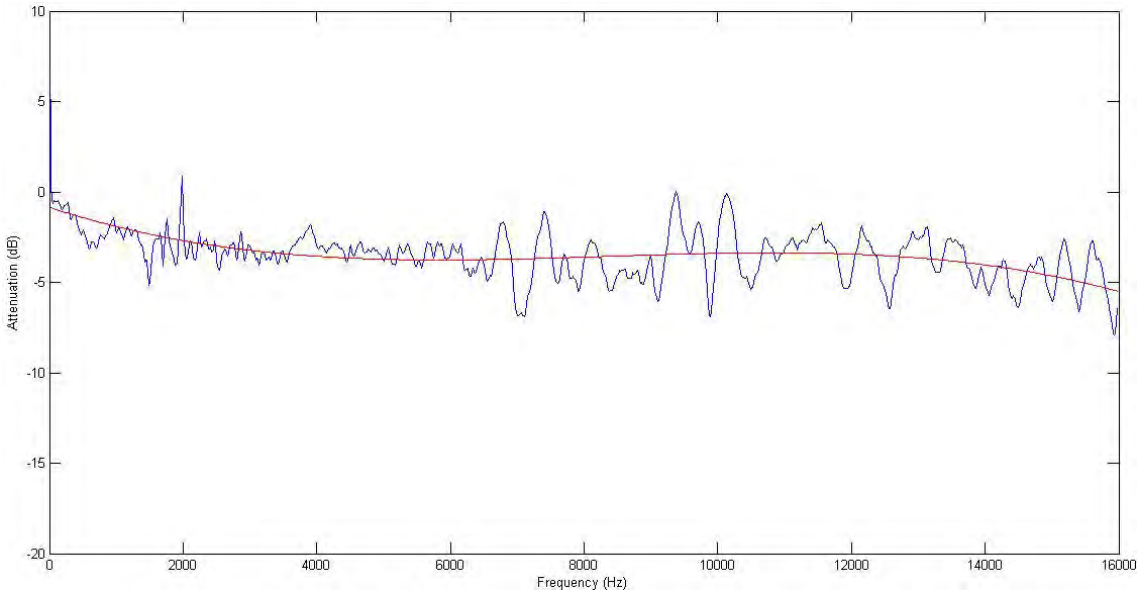

Fig. B. 94: Attenuation for ClearPix 2 White 1.0 with screen angled 25 degrees. Mic position 15 deg

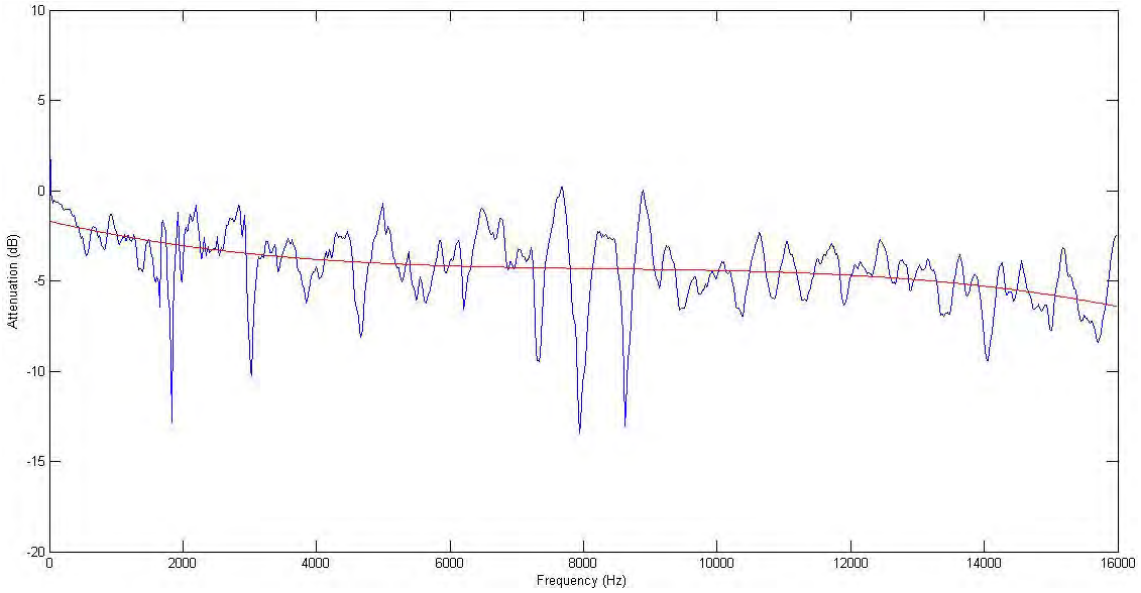

Fig. B. 95: Attenuation for ClearPix 2 White 1.0 with screen angled 25 degrees. Mic position 30 deg

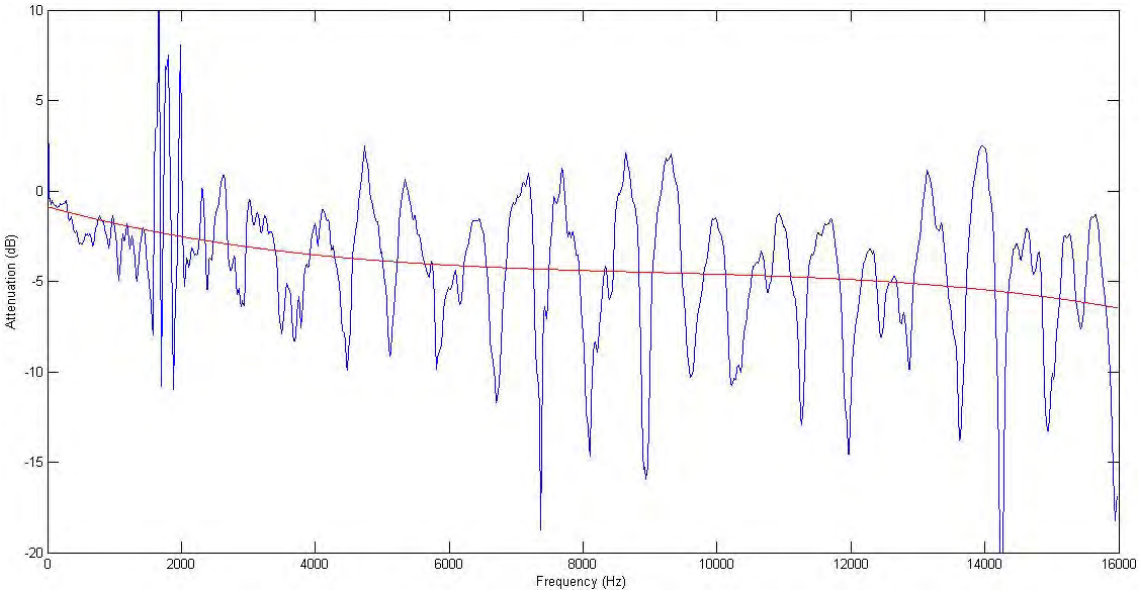

Fig. B. 96: Attenuation for ClearPix 2 White 1.0 with screen angled 25 degrees. Mic position 45 deg

Appendix C

Cepstrum

C. 1. Enlightor 4K

Cepstrum analysis for screen Enlightor 4K at a distance of 2 cm

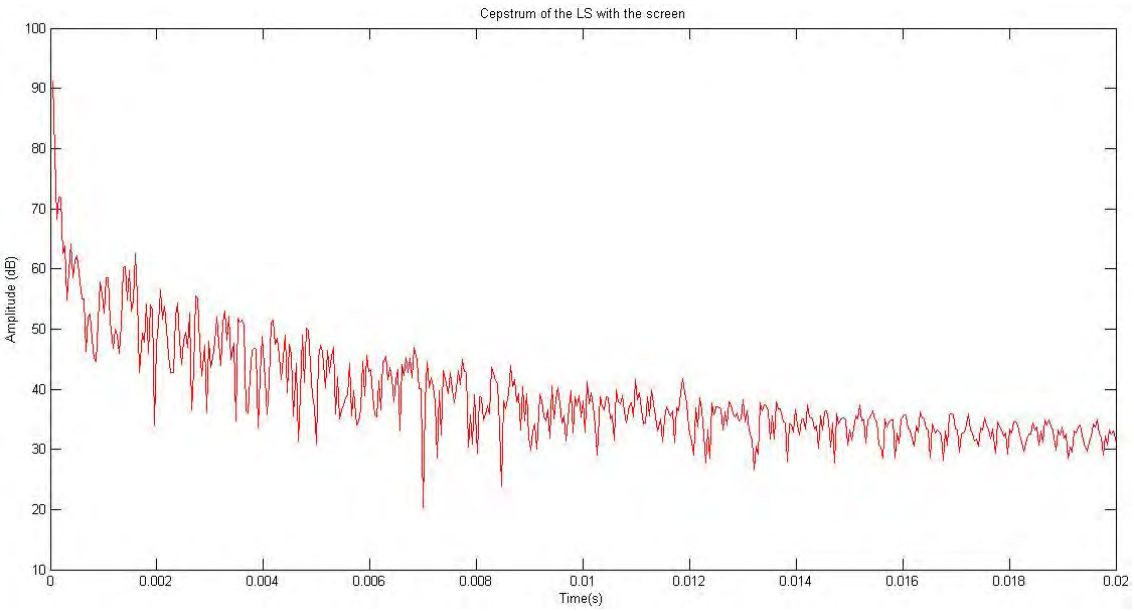

Fig. C. 1: Cepstrum analysis for Enlightor 4K at a distance of 2 cm. 0 degrees

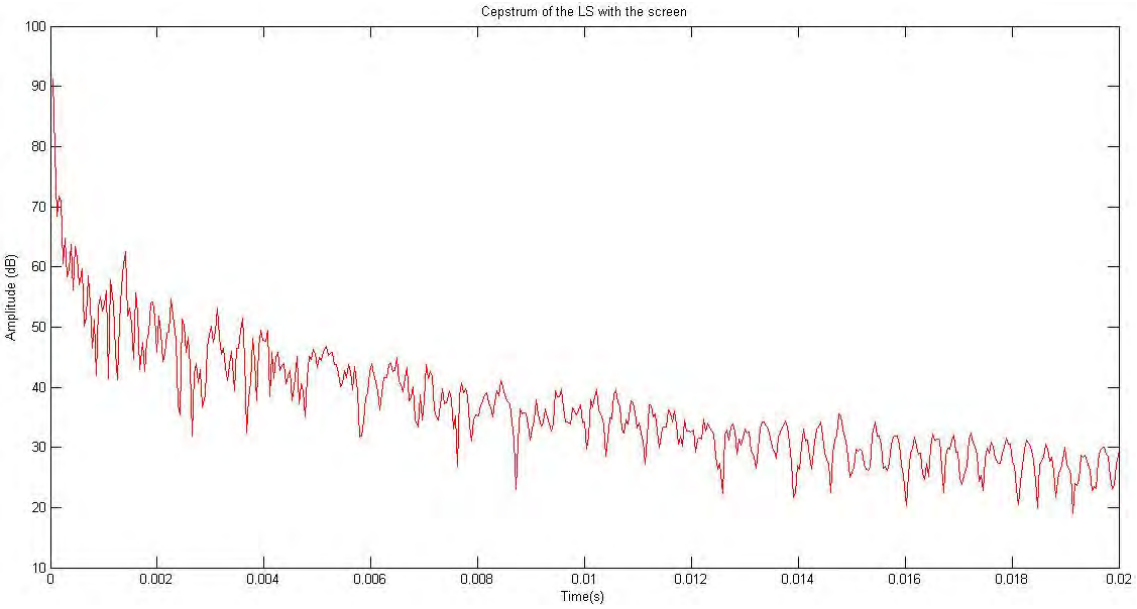

Fig. C. 2: Cepstrum analysis for Enlightor 4K at a distance of 2 cm. 15 degrees

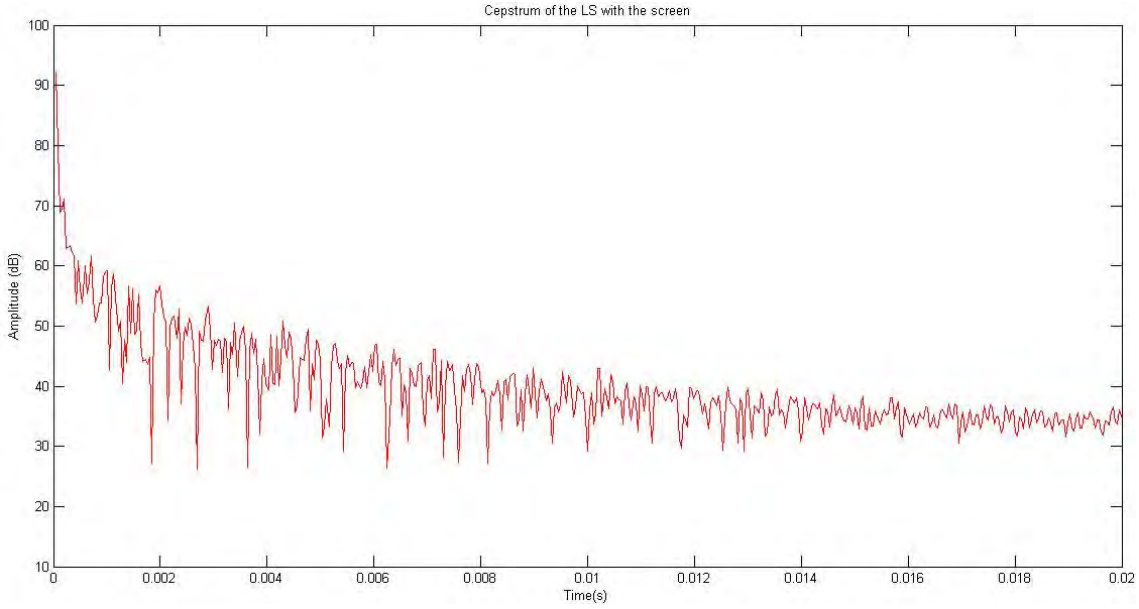

Fig. C. 3: Cepstrum analysis for Enlightor 4K at a distance of 2 cm. 30 degrees

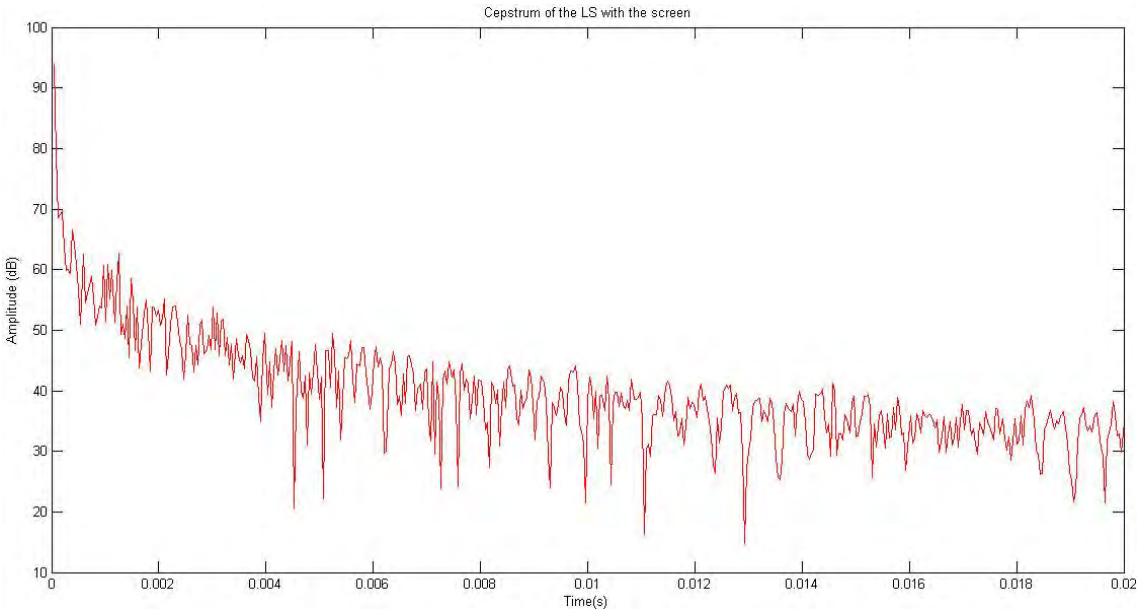

Fig. C. 4: Cepstrum analysis for Enlightor 4K at a distance of 2 cm. 45 degrees

Cepstrum analysis for screen Enlightor 4K at a distance of 7 cm

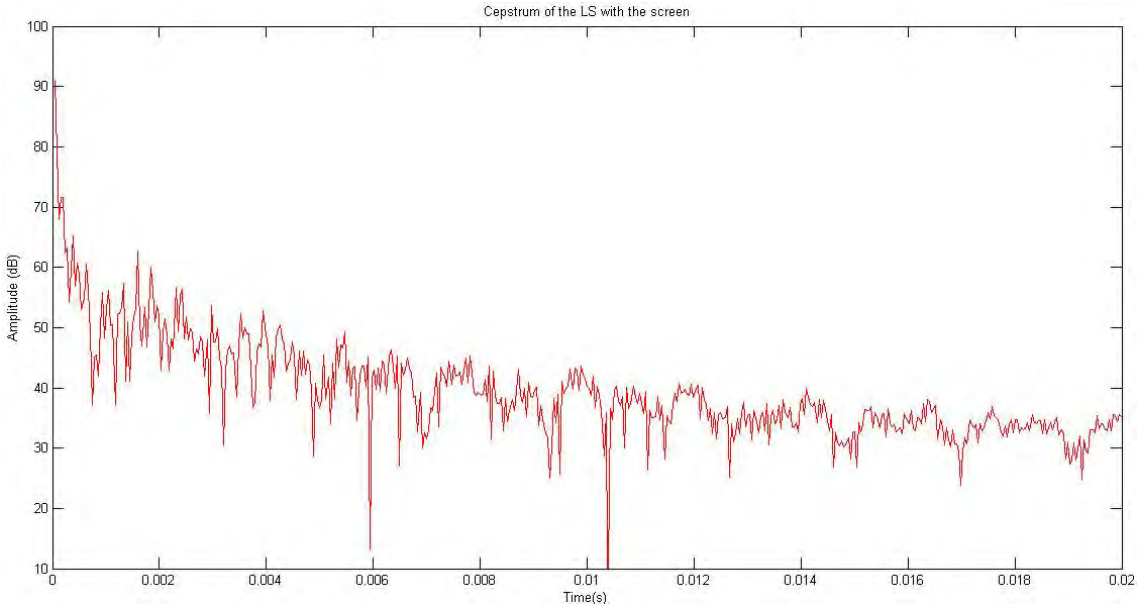

Fig. C. 5: Cepstrum analysis for Enlightor 4K at a distance of 7 cm. 0 degrees

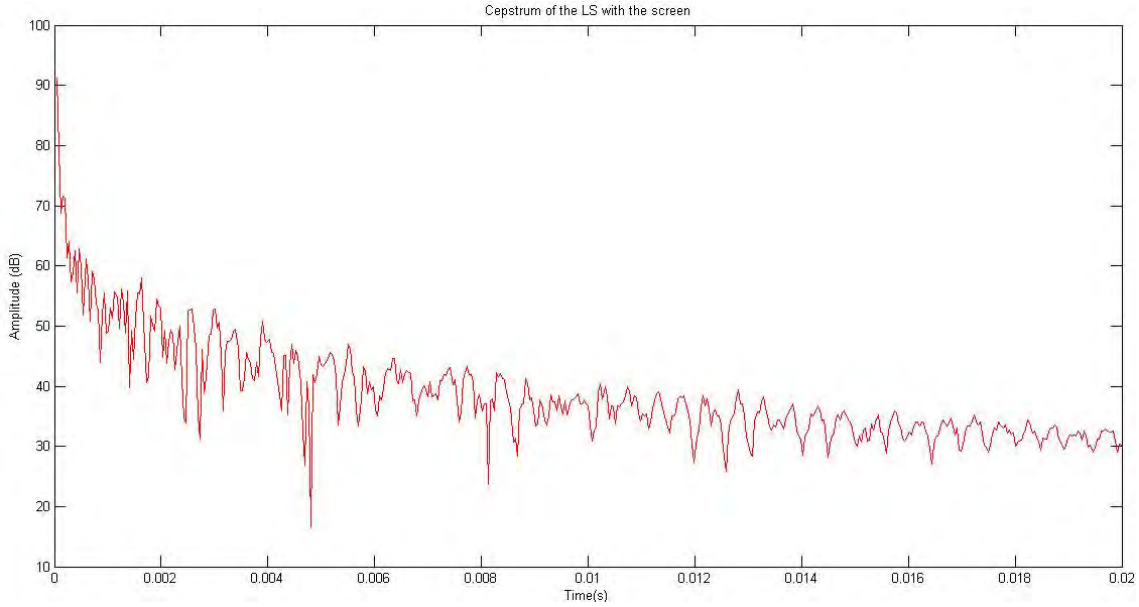

Fig. C. 6: Cepstrum analysis for Enlightor 4K at a distance of 7 cm. 15 degrees

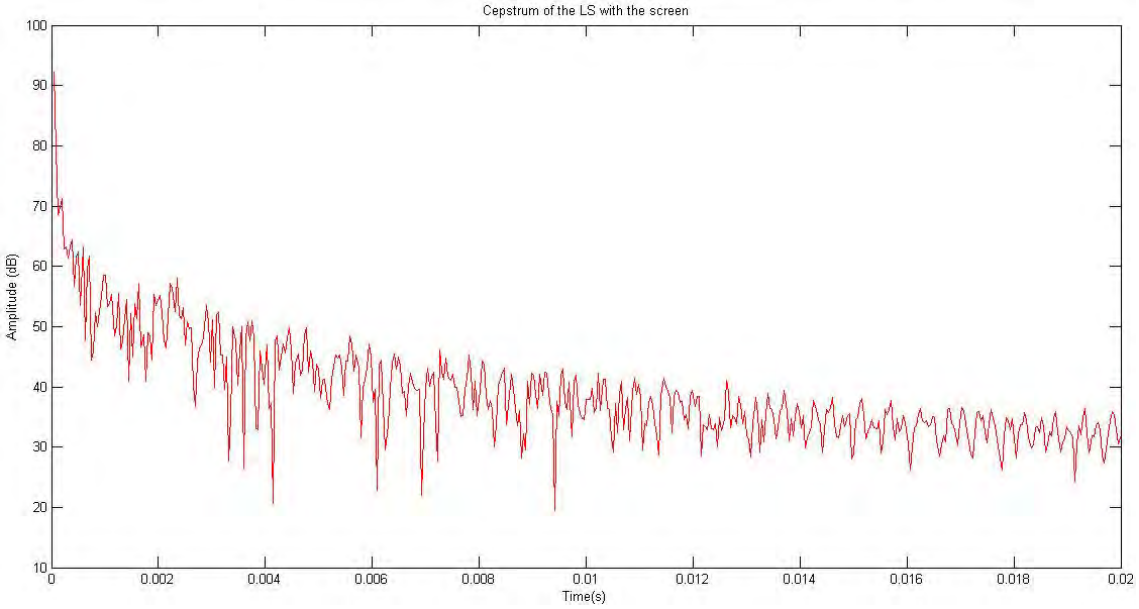

Fig. C. 7: Cepstrum analysis for Enlightor 4K at a distance of 7 cm. 30 degrees

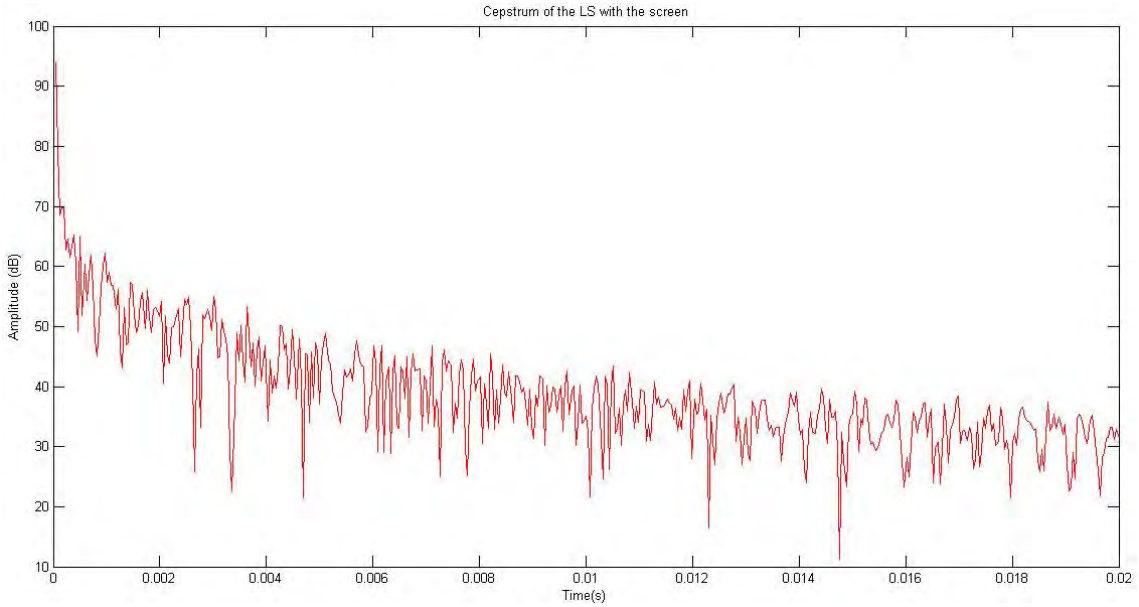

Fig. C. 8: Cepstrum analysis for Enlightor 4K at a distance of 7 cm. 45 degrees

Cepstrum analysis for screen Enlightor 4K at a distance of 15 cm

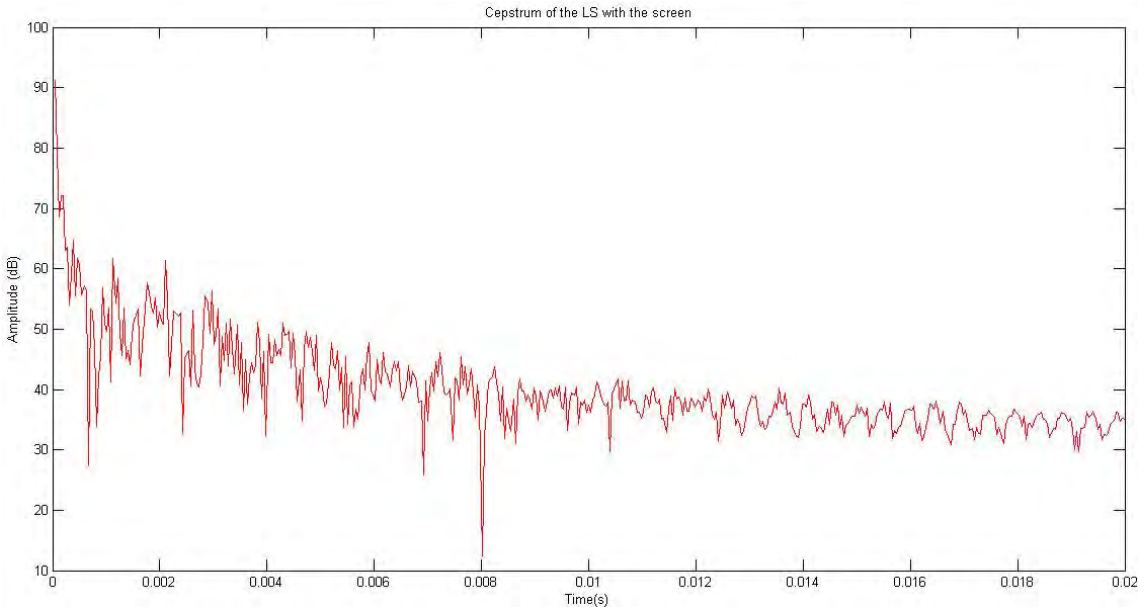

Fig. C. 9: Cepstrum analysis for Enlightor 4K at a distance of 15 cm. 0 degrees

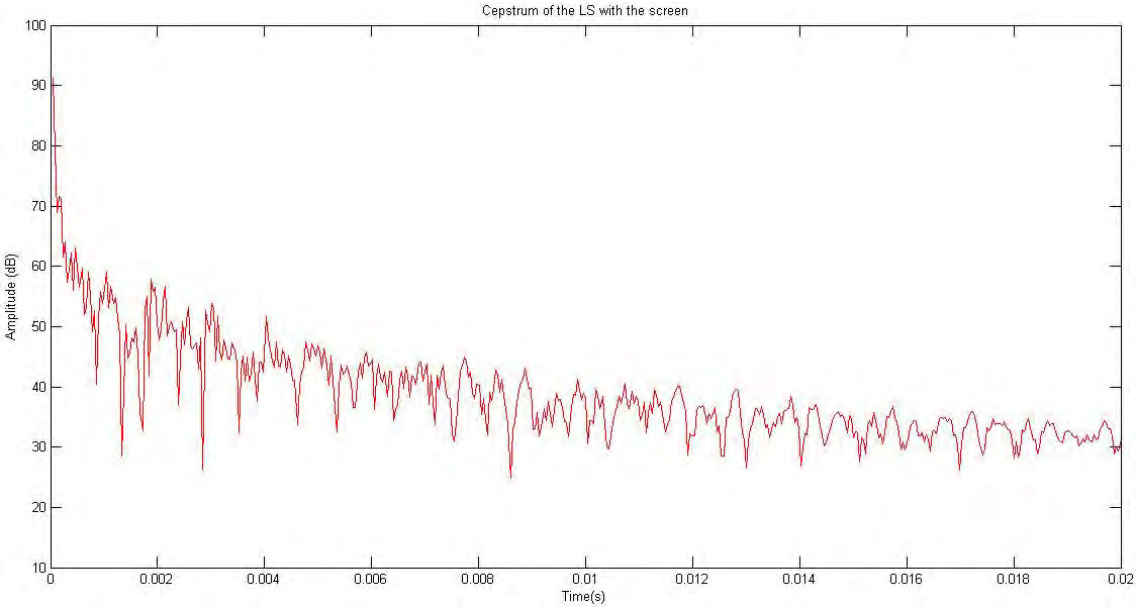

Fig. C. 10: Cepstrum analysis for Enlightor 4K at a distance of 15 cm. 15 degrees

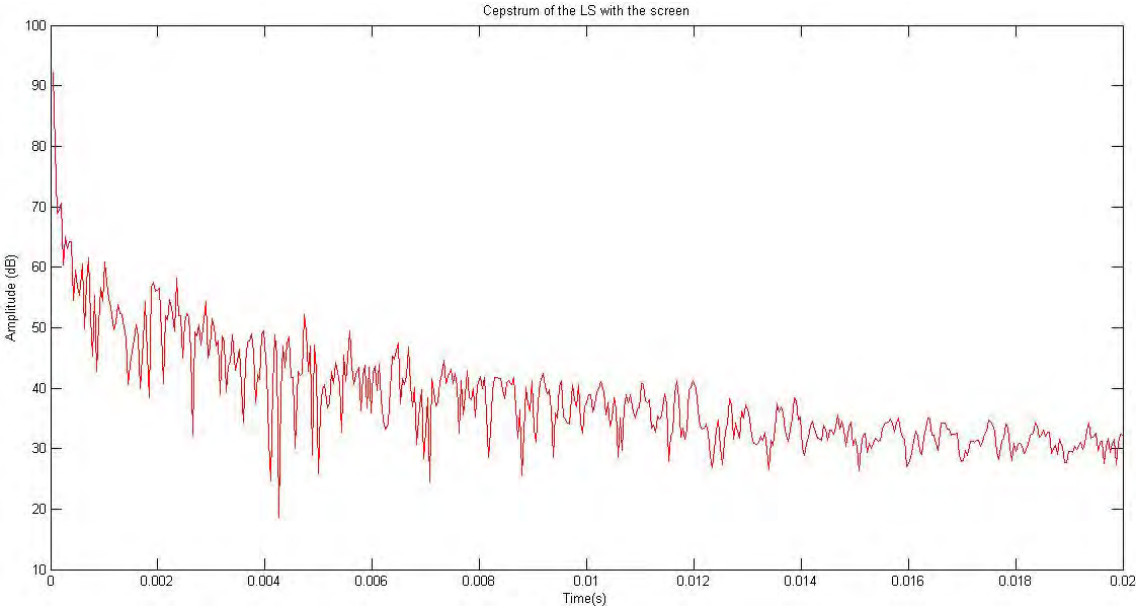

Fig. C. 11: Cepstrum analysis for Enlightor 4K at a distance of 15 cm. 30 degrees

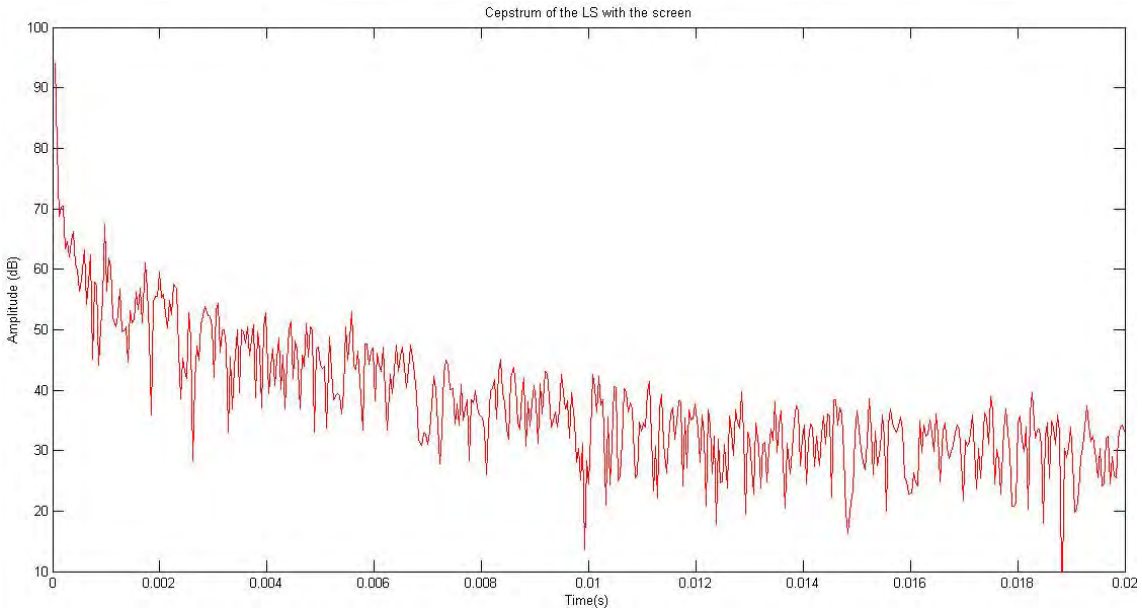

Fig. C. 12: Cepstrum analysis for Enlightor 4K at a distance of 15 cm. 45 degrees

Cepstrum analysis for screen Enlightor 4K at a distance of 30 cm

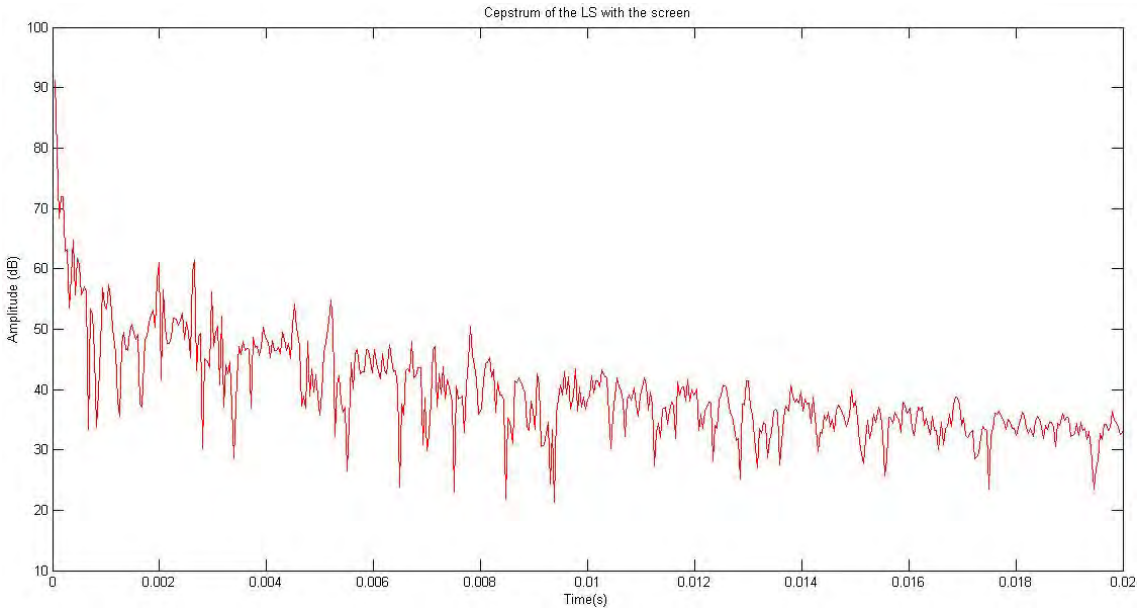

Fig. C. 13: Cepstrum analysis for Enlightor 4K at a distance of 30 cm. 0 degrees

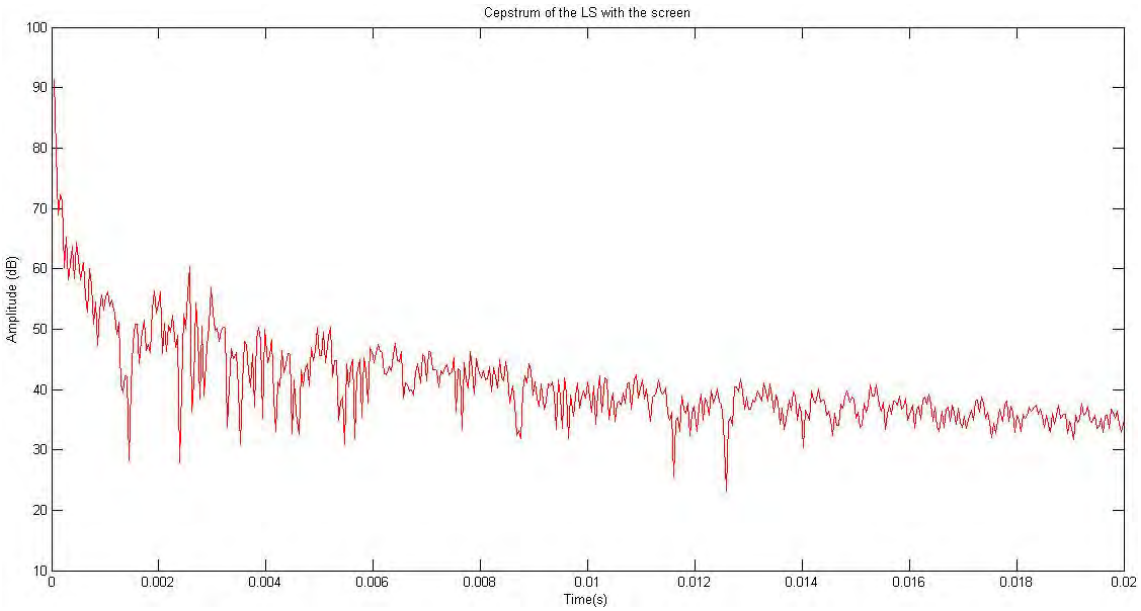

Fig. C. 14: Cepstrum analysis for Enlightor 4K at a distance of 30 cm. 15 degrees

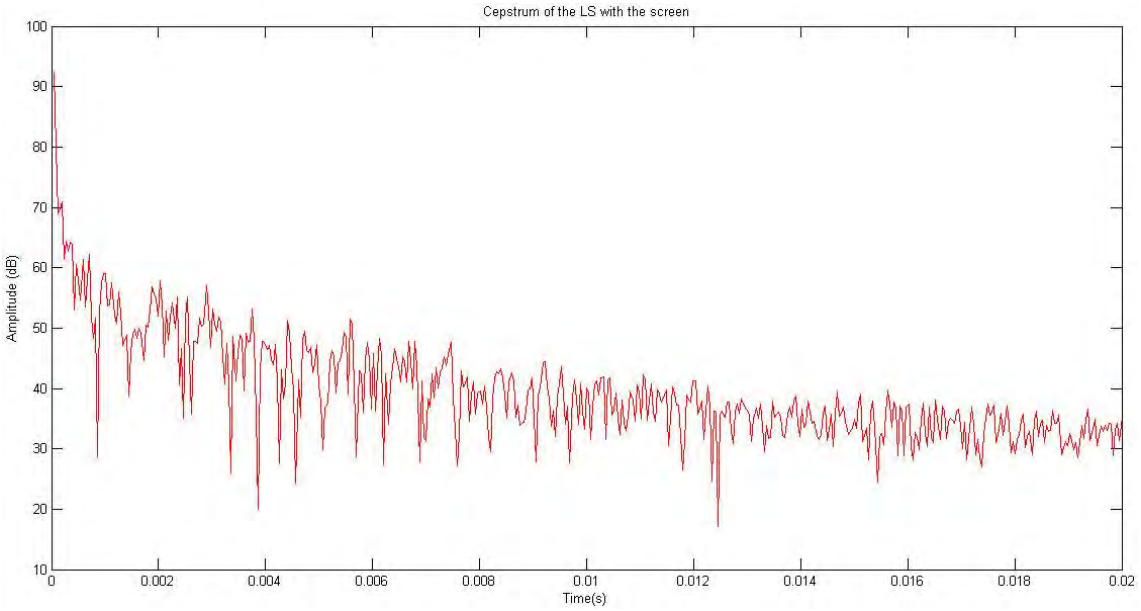

Fig. C. 15: Cepstrum analysis for Enlightor 4K at a distance of 30 cm. 30 degrees

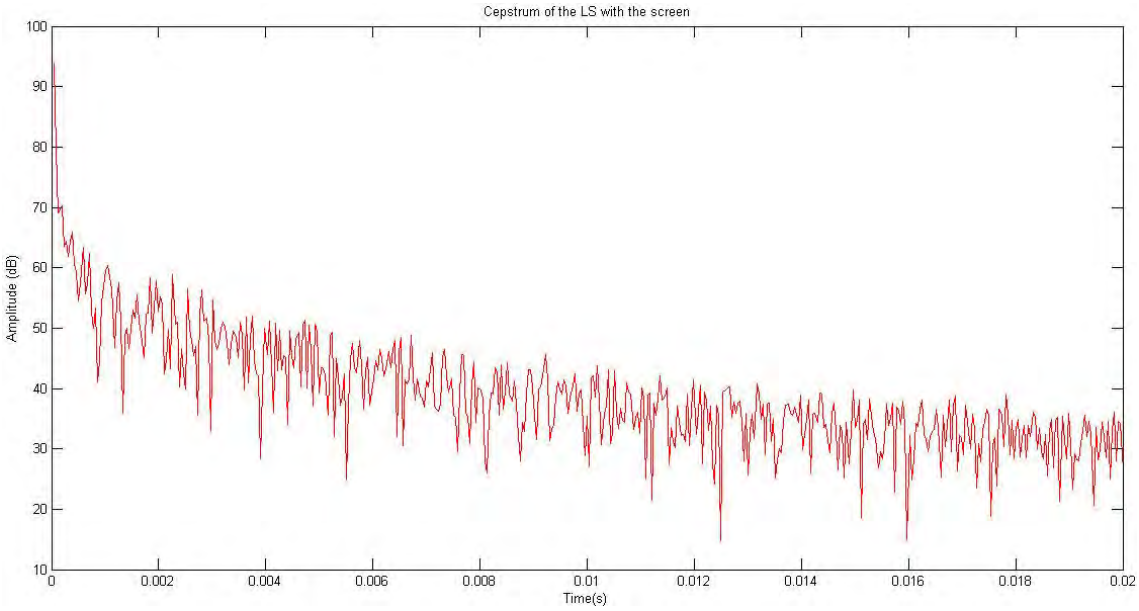

Fig. C. 16: Cepstrum analysis for Enlightor 4K at a distance of 30 cm. 45 degrees

Cepstrum analysis for screen Enlightor 4K at a distance of 45 cm

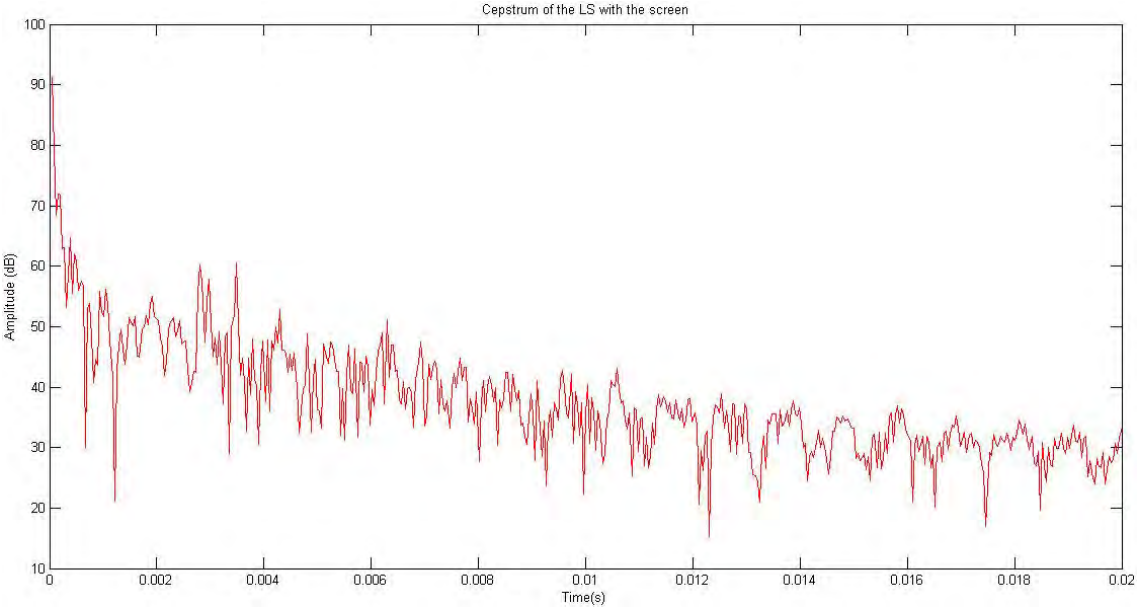

Fig. C. 17: Cepstrum analysis for Enlightor 4K at a distance of 45 cm. 0 degrees

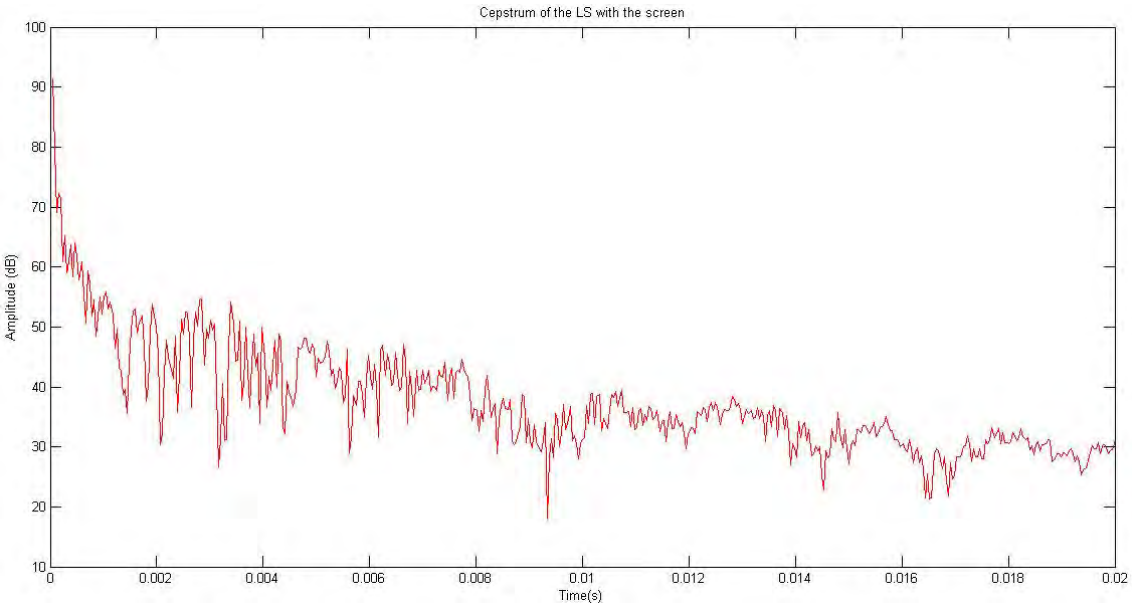

Fig. C. 18: Cepstrum analysis for Enlightor 4K at a distance of 45 cm. 15 degrees

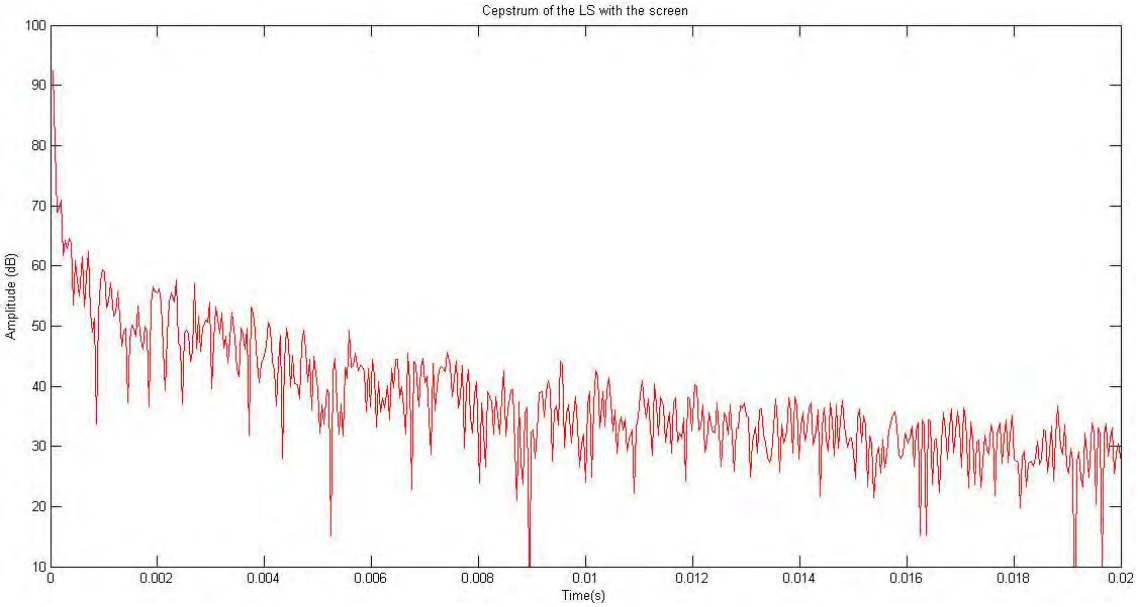

Fig. C. 19: Cepstrum analysis for Enlightor 4K at a distance of 45 cm. 30 degrees

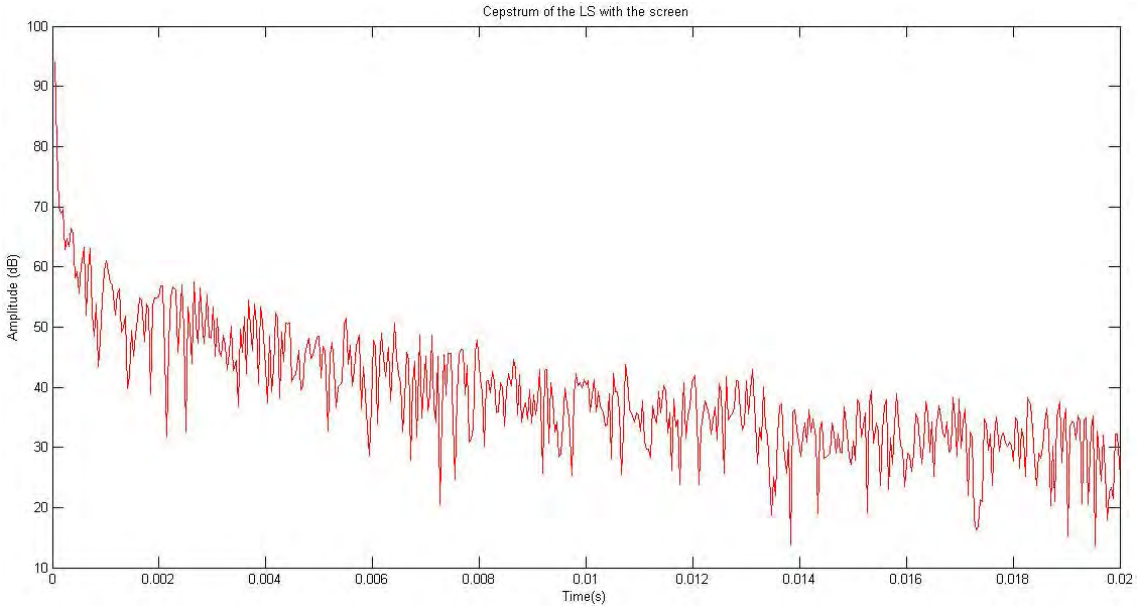

Fig. C. 20: Cepstrum analysis for Enlightor 4K at a distance of 45 cm. 45 degrees

Cepstrum analysis for screen Enlightor 4K at a distance of 60 cm

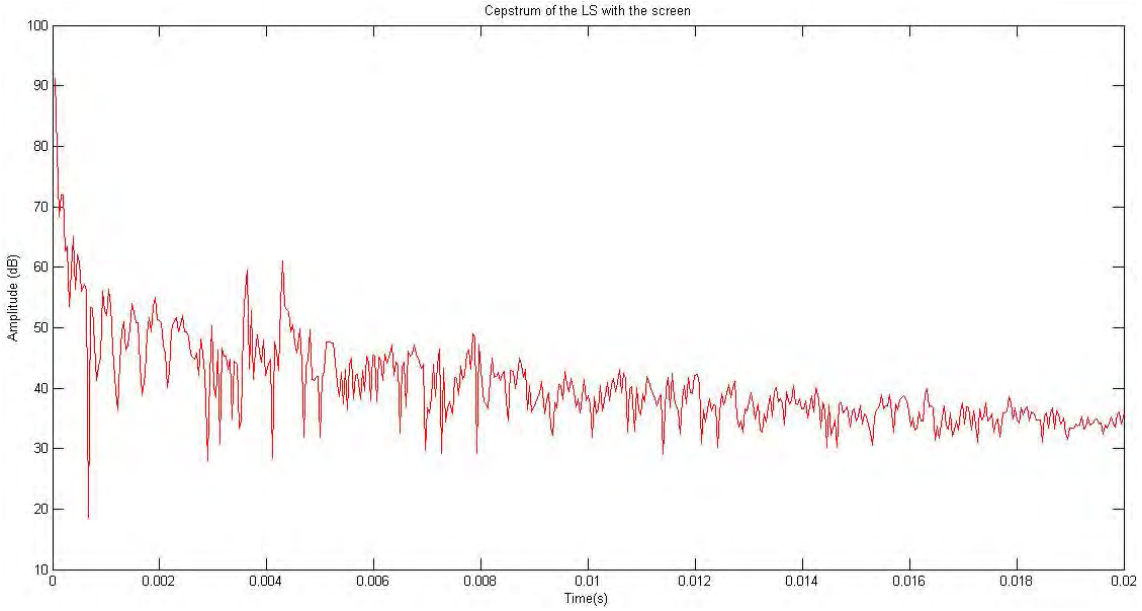

Fig. C. 21: Cepstrum analysis for Enlightor 4K at a distance of 60 cm. 0 degrees

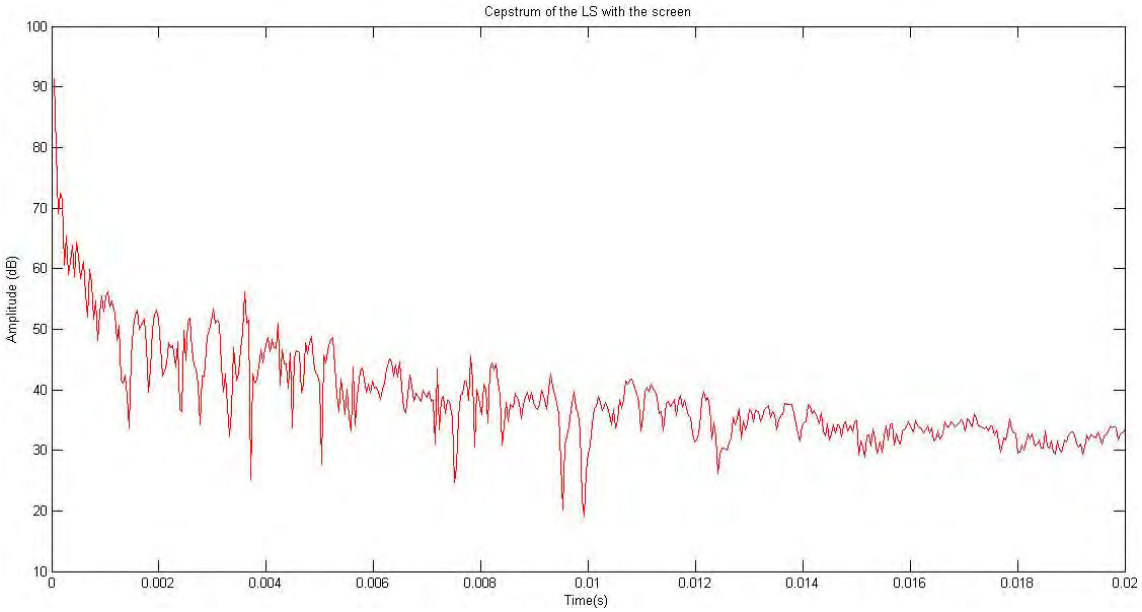

Fig. C. 22: Cepstrum analysis for Enlightor 4K at a distance of 60 cm. 15 degrees

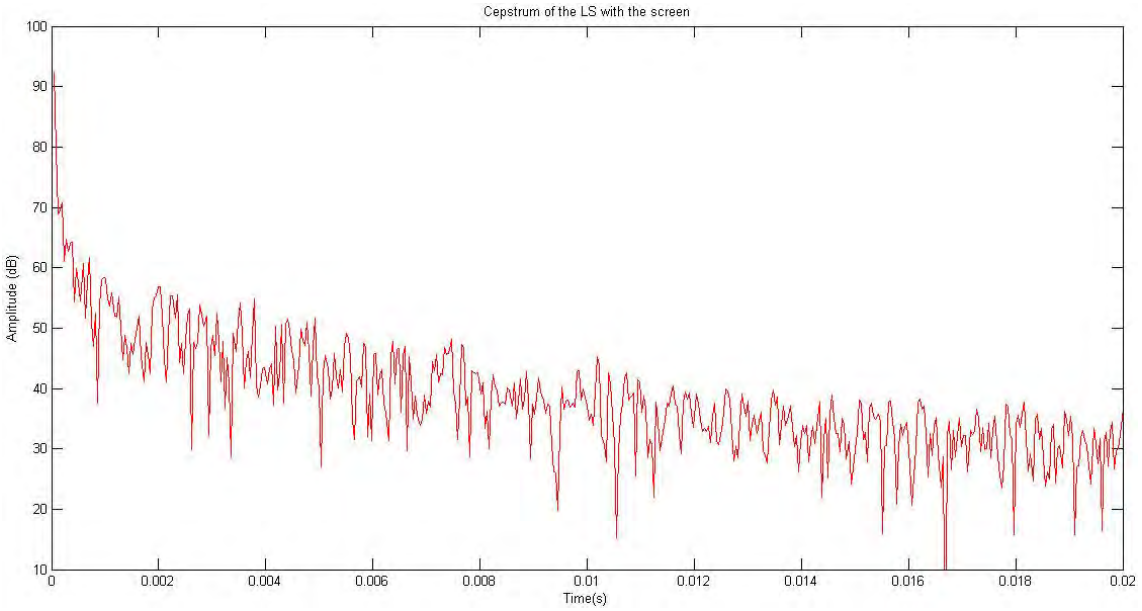

Fig. C. 23: Cepstrum analysis for Enlightor 4K at a distance of 60 cm. 30 degrees

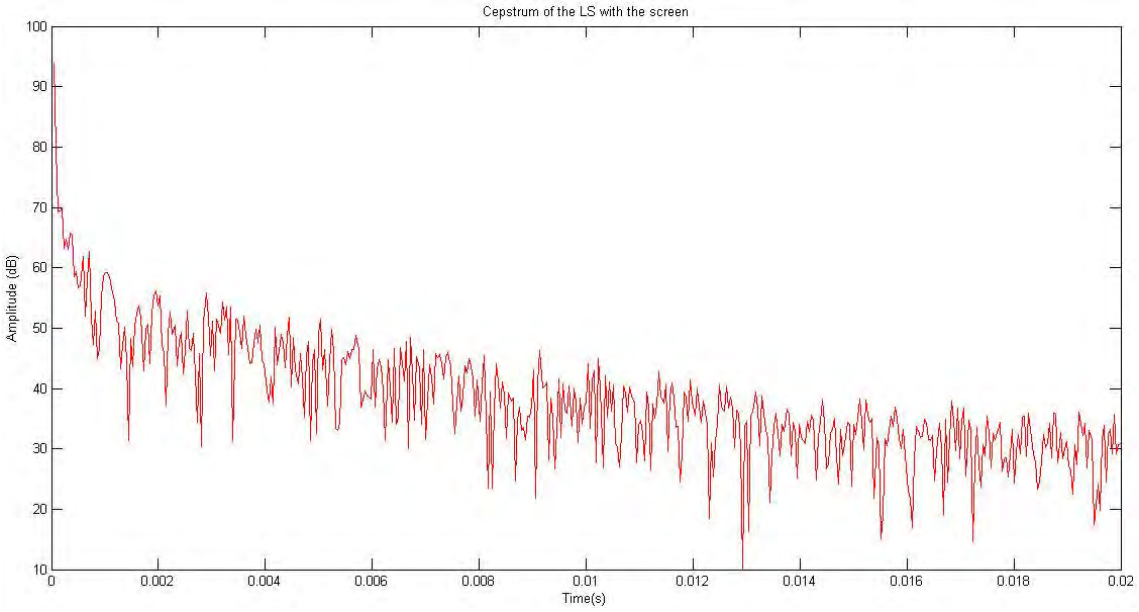

Fig. C. 24: Cepstrum analysis for Enlightor 4K at a distance of 60 cm. 45 degrees

Cepstrum analysis for screen Enlightor 4K with screen angled 10 deg

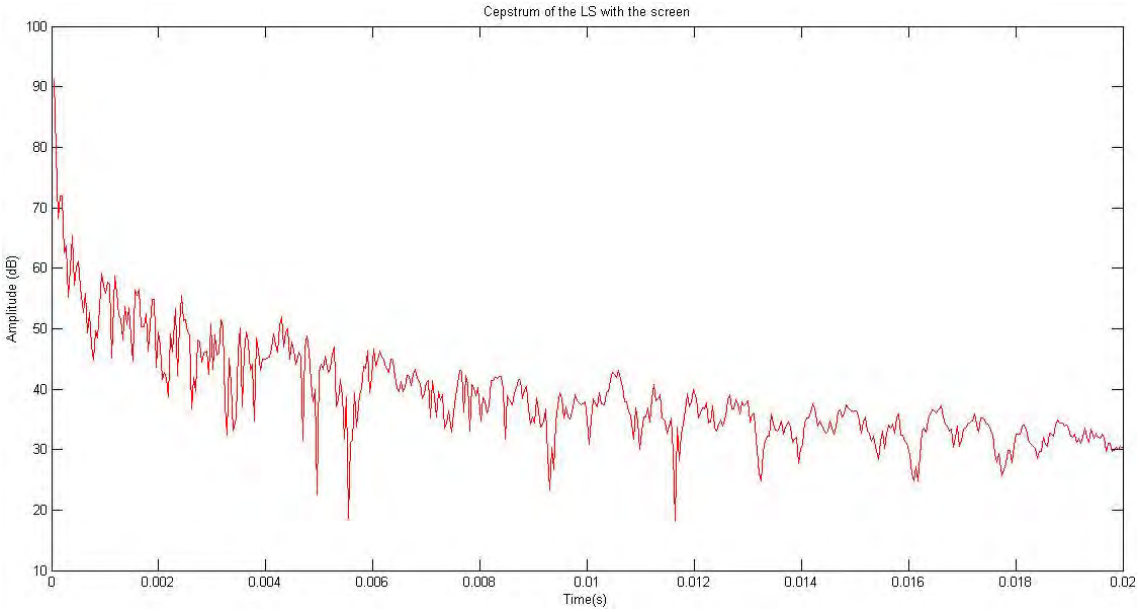

Fig. C. 25: Cepstrum analysis for Enlightor 4K with screen angled 10 degrees. Mic position 0 deg

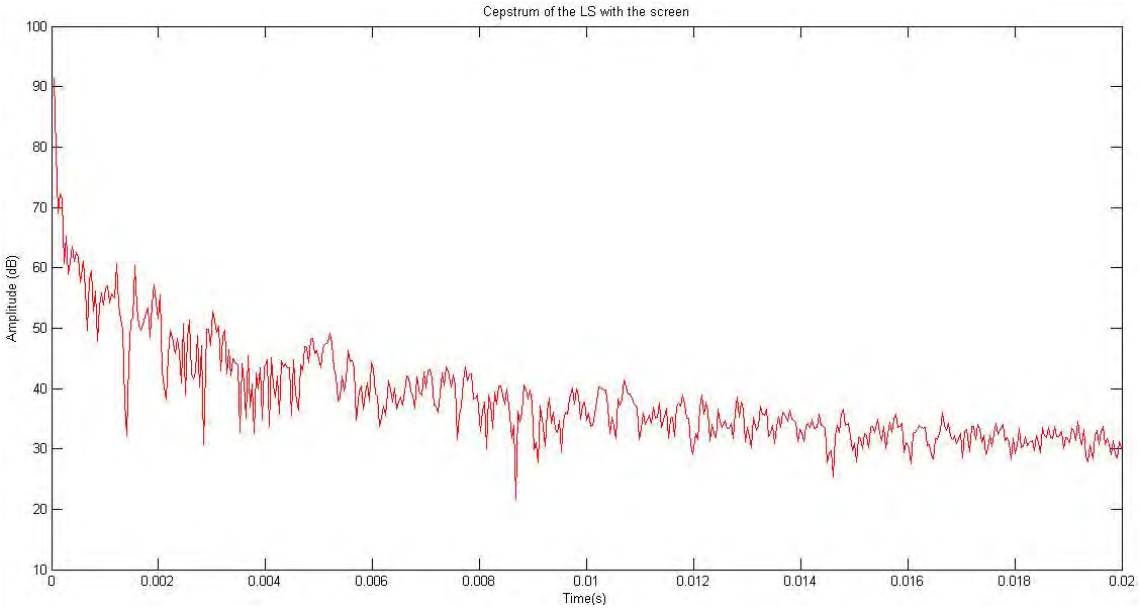

Fig. C. 26: Cepstrum analysis for Enlightor 4K with screen angled 10 degrees. Mic position 15 deg

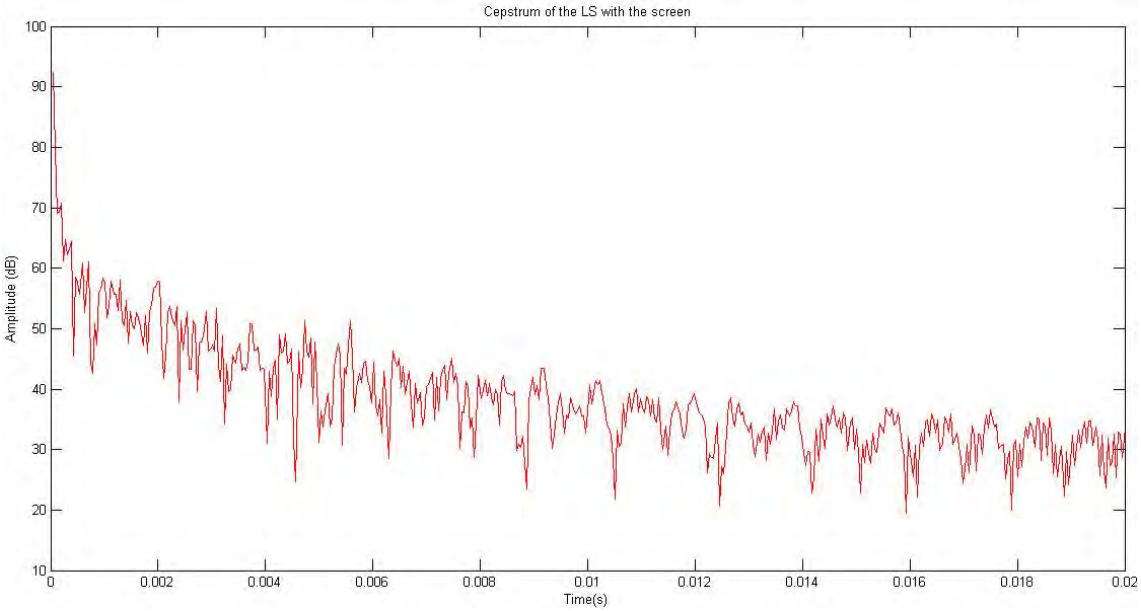

Fig. C. 27: Cepstrum analysis for Enlightor 4K with screen angled 10 degrees. Mic position 30 deg

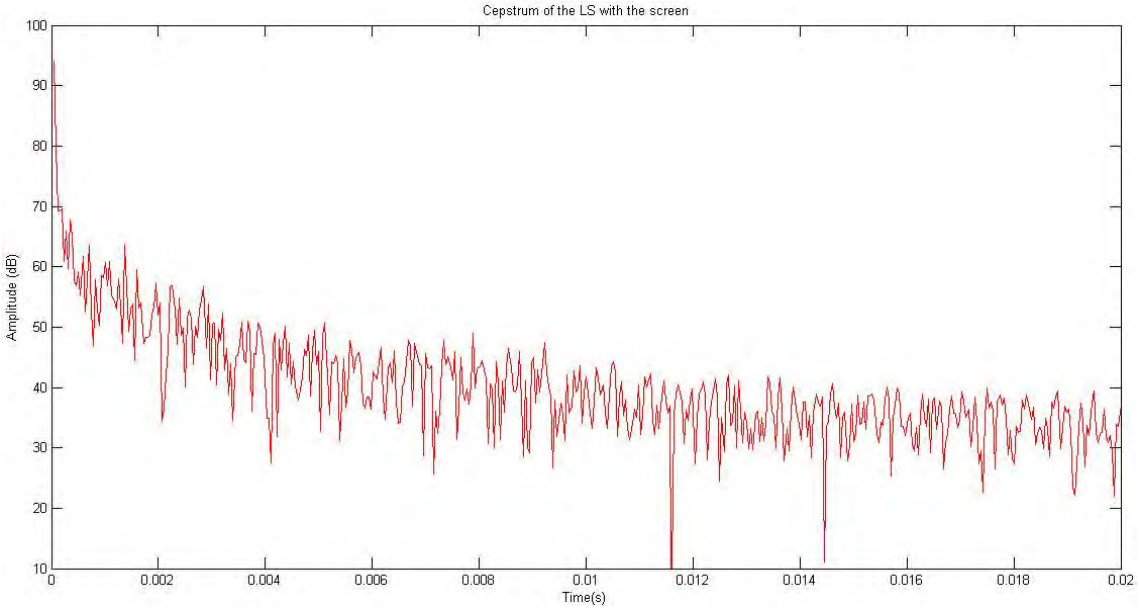

Fig. C. 28: Cepstrum analysis for Enlightor 4K with screen angled 10 degrees. Mic position 45 deg

Cepstrum analysis for screen Enlightor 4K with screen angled 25 deg

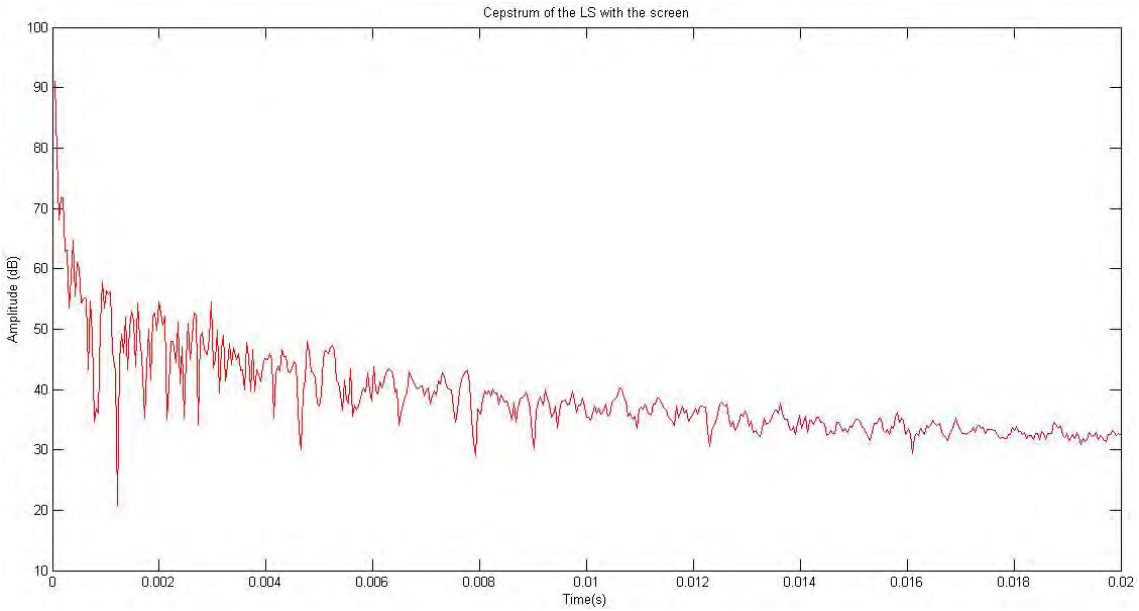

Fig. C. 29: Cepstrum analysis for Enlightor 4K with screen angled 25 degrees. Mic position 0 deg

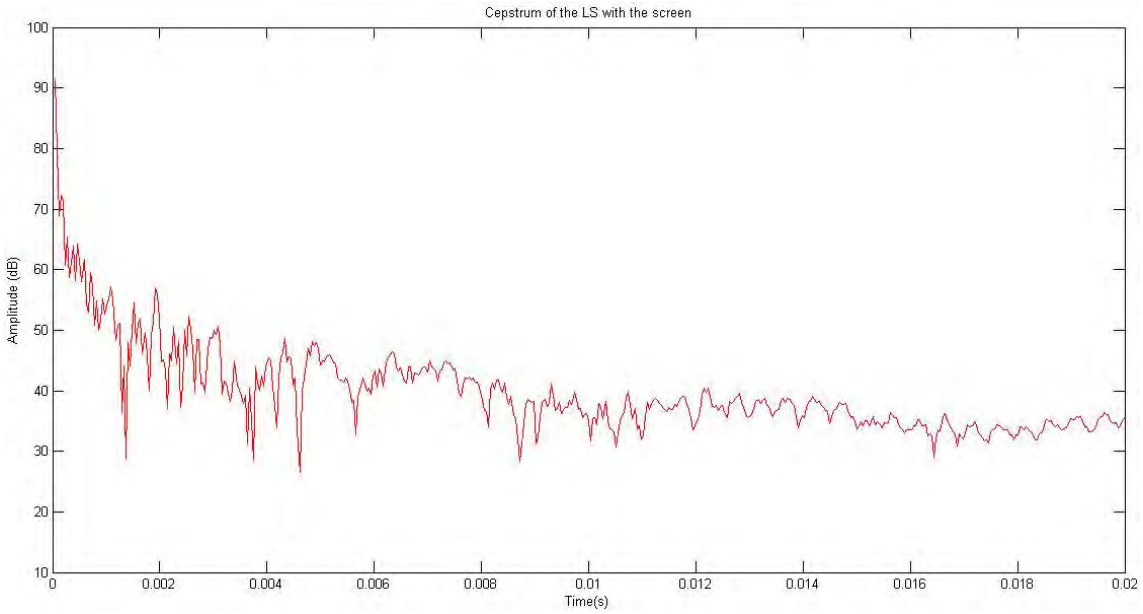

Fig. C. 30: Cepstrum analysis for Enlightor 4K with screen angled 25 degrees. Mic position 15 deg

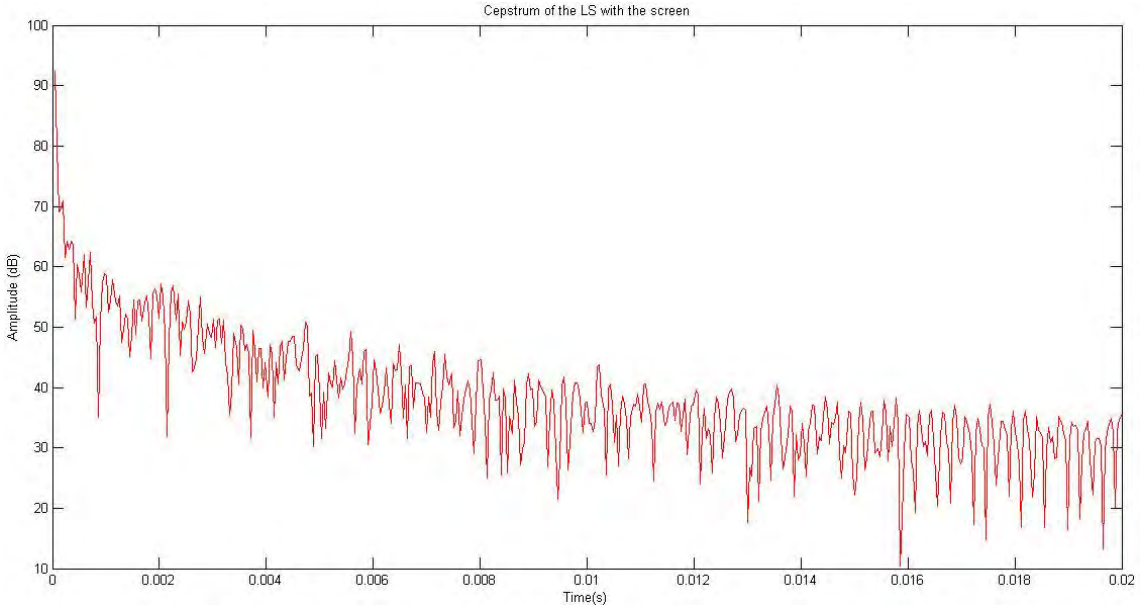

Fig. C. 31: Cepstrum analysis for Enlightor 4K with screen angled 25 degrees. Mic position 30 deg

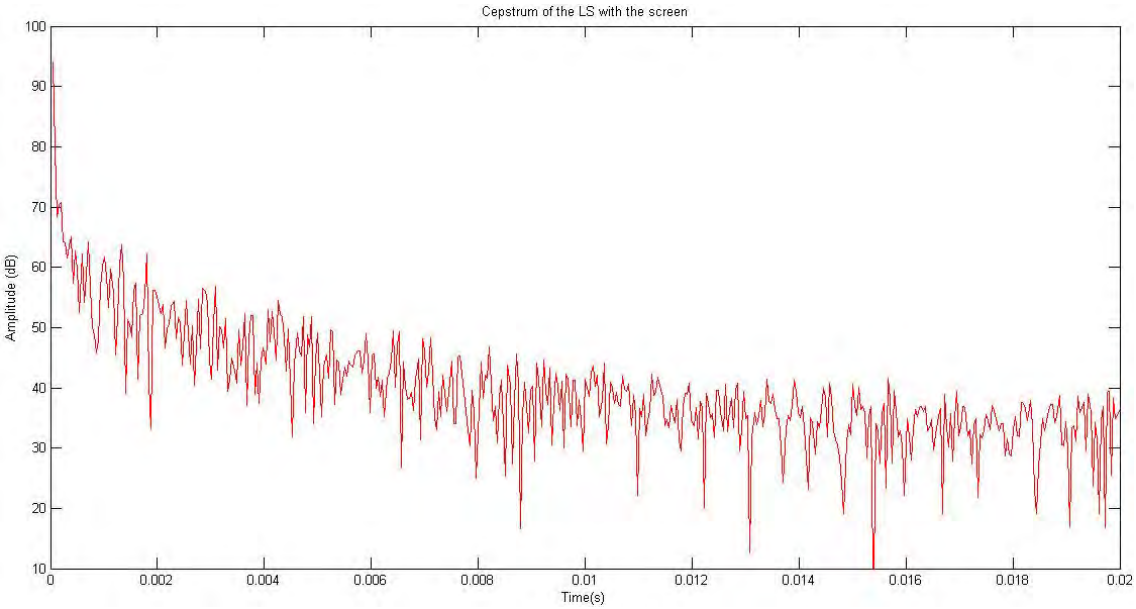

Fig. C. 32: Cepstrum analysis for Enlightor 4K with screen angled 25 degrees. Mic position 45 deg

C. 2. Matt Plus MiniPerforated

Cepstrum analysis for screen Matt Plus MiniPerforated at a distance of 2 cm

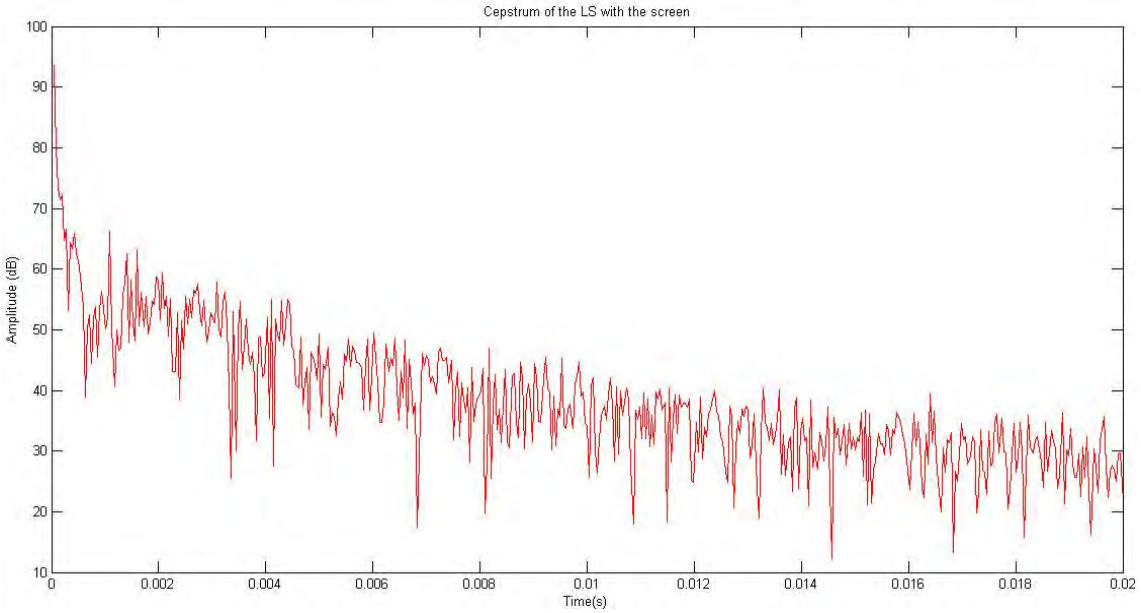

Fig. C. 33: Cepstrum analysis for Matt Plus MiniPerforated at a distance of 2 cm. 0 degrees

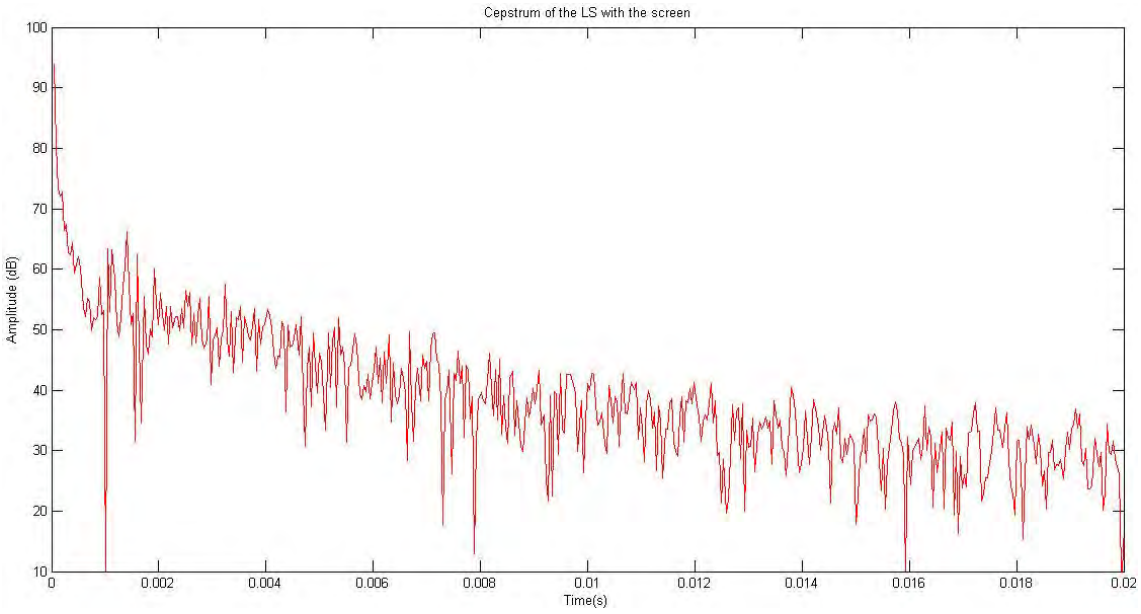

Fig. C. 34: Cepstrum analysis for Matt Plus MiniPerforated at a distance of 2 cm. 15 degrees

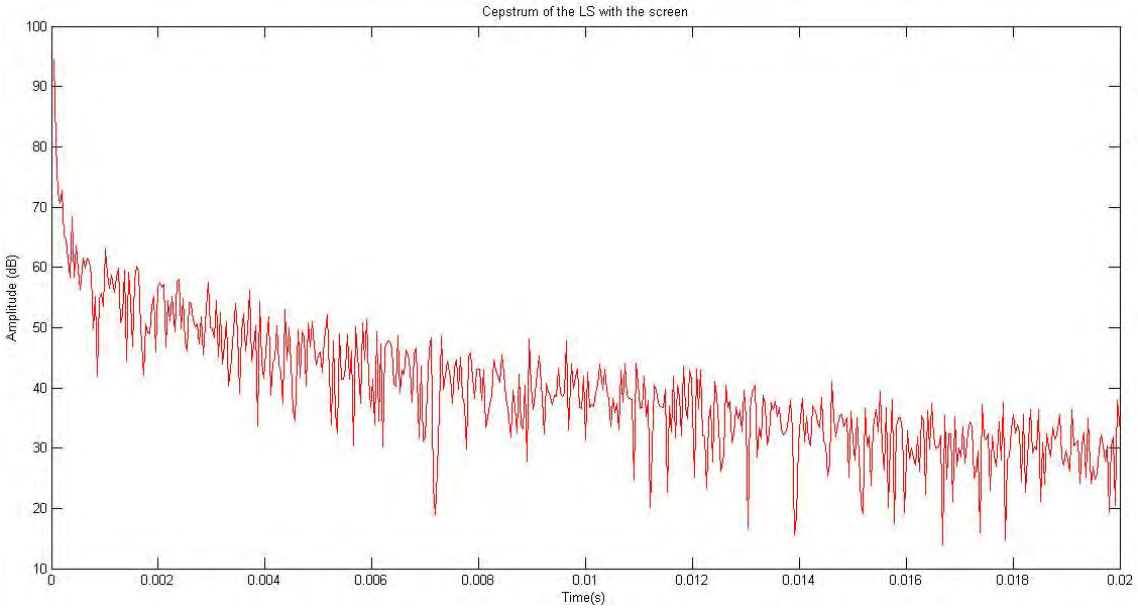

Fig. C. 35: Cepstrum analysis for Matt Plus MiniPerforated at a distance of 2 cm. 30 degrees

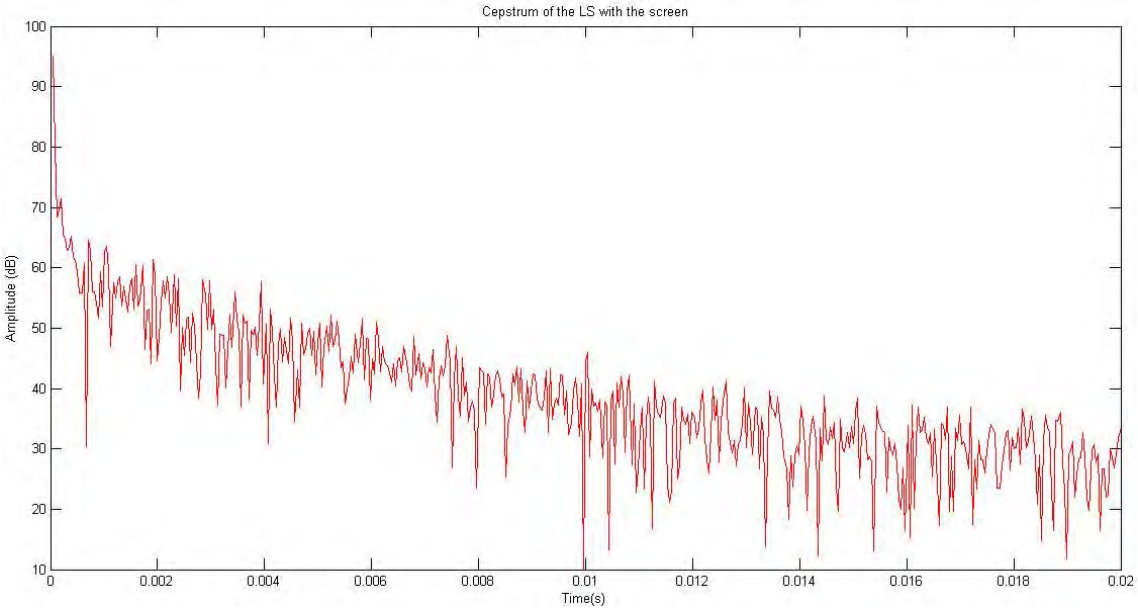

Fig. C. 36: Cepstrum analysis for Matt Plus MiniPerforated at a distance of 2 cm. 45 degrees

Cepstrum analysis for screen Matt Plus MiniPerforated at a distance of 7 cm

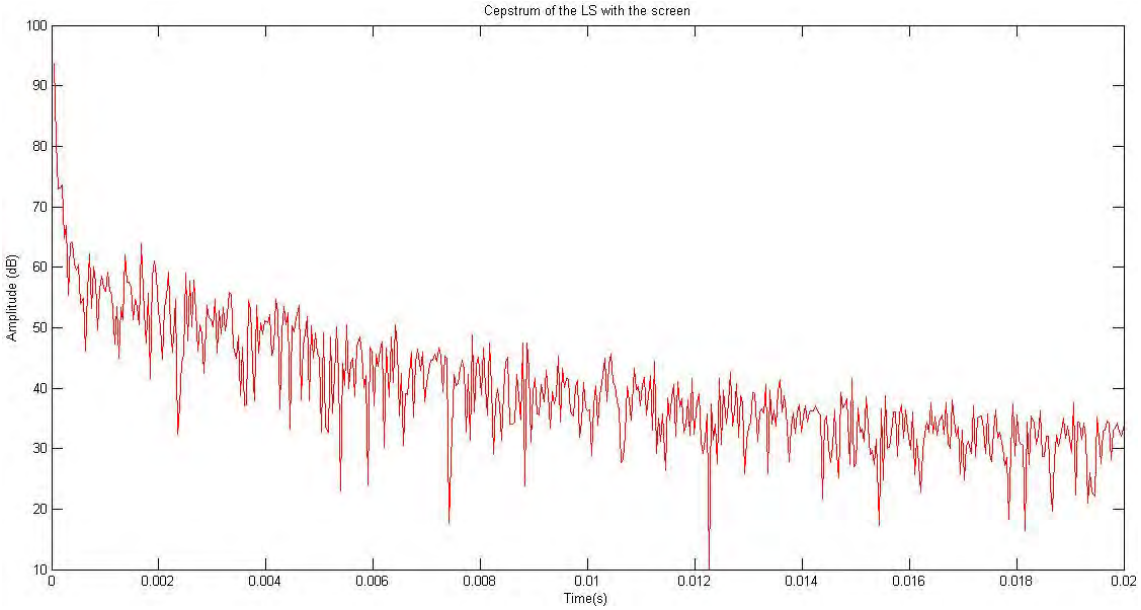

Fig. C. 37: Cepstrum analysis for Matt Plus MiniPerforated at a distance of 7 cm. 0 degrees

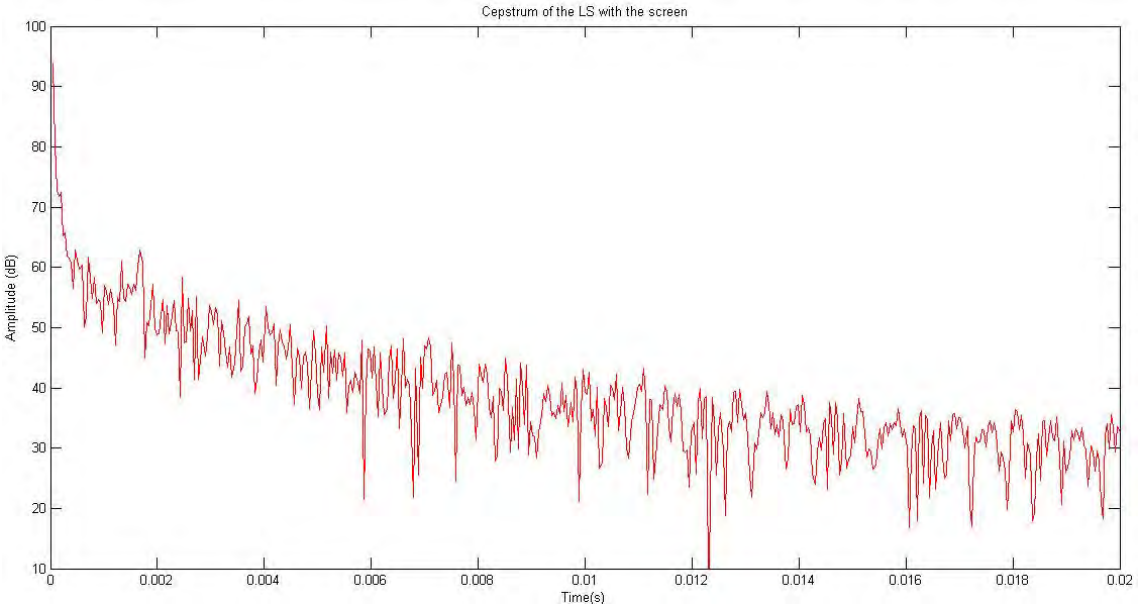

Fig. C. 38: Cepstrum analysis for Matt Plus MiniPerforated at a distance of 7 cm. 15 degrees

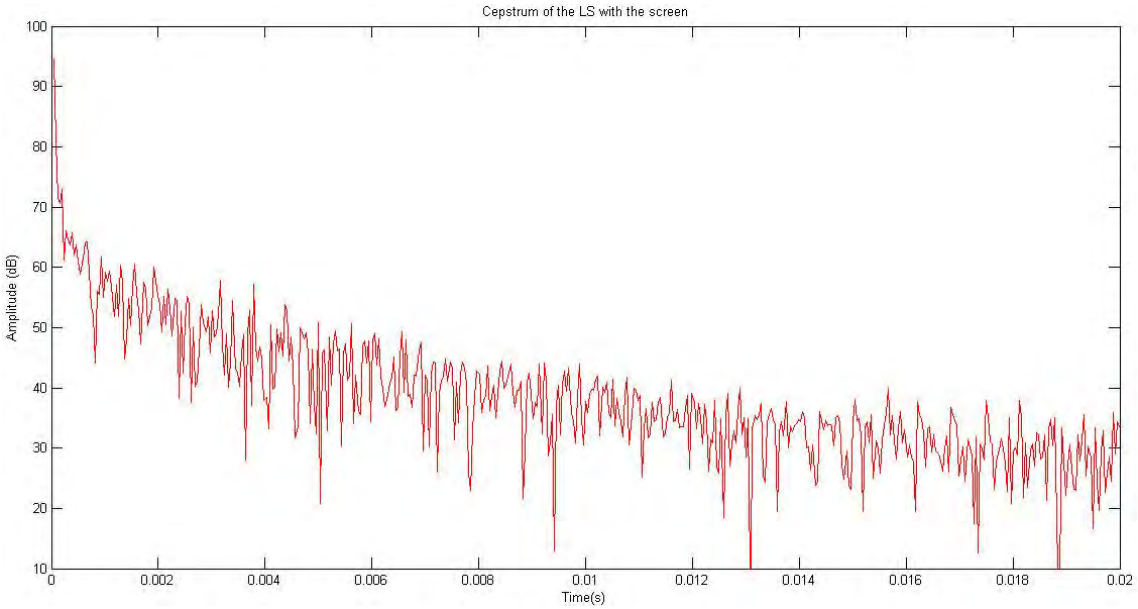

Fig. C. 39: Cepstrum analysis for Matt Plus MiniPerforated at a distance of 7 cm. 30 degrees

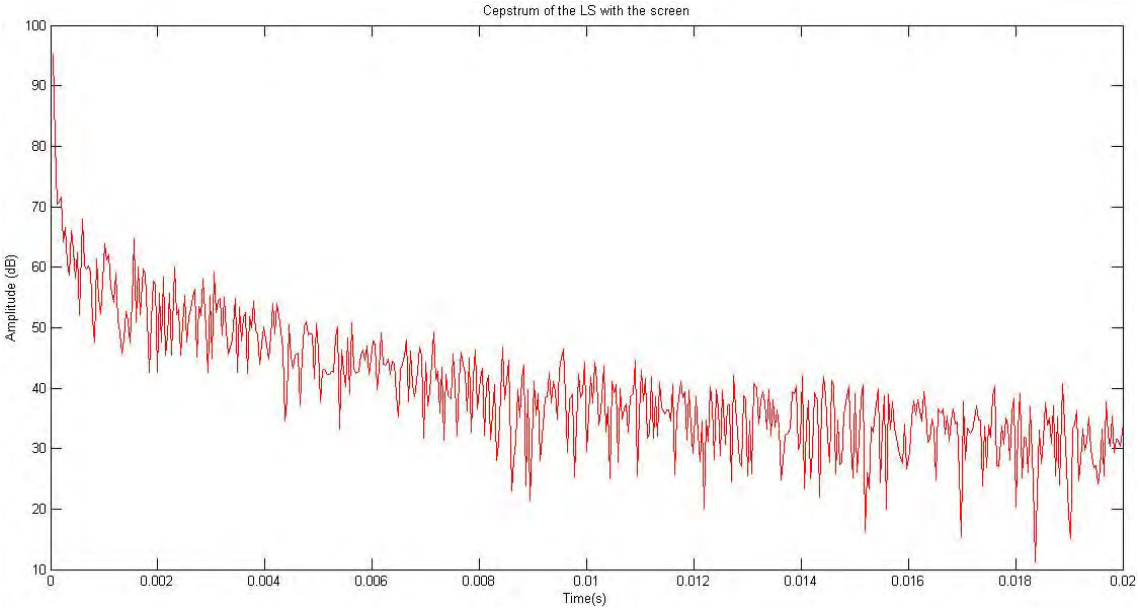

Fig. C. 40: Cepstrum analysis for Matt Plus MiniPerforated at a distance of 7 cm. 45 degrees

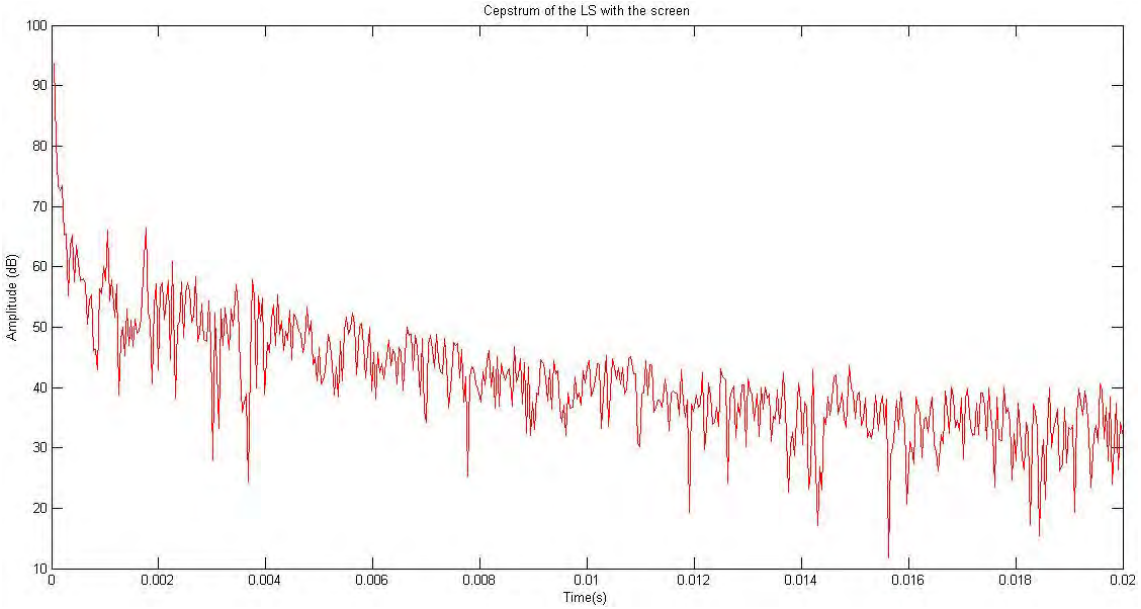

Fig. C. 41: Cepstrum analysis for Matt Plus MiniPerforated at a distance of 15 cm. 0 degrees

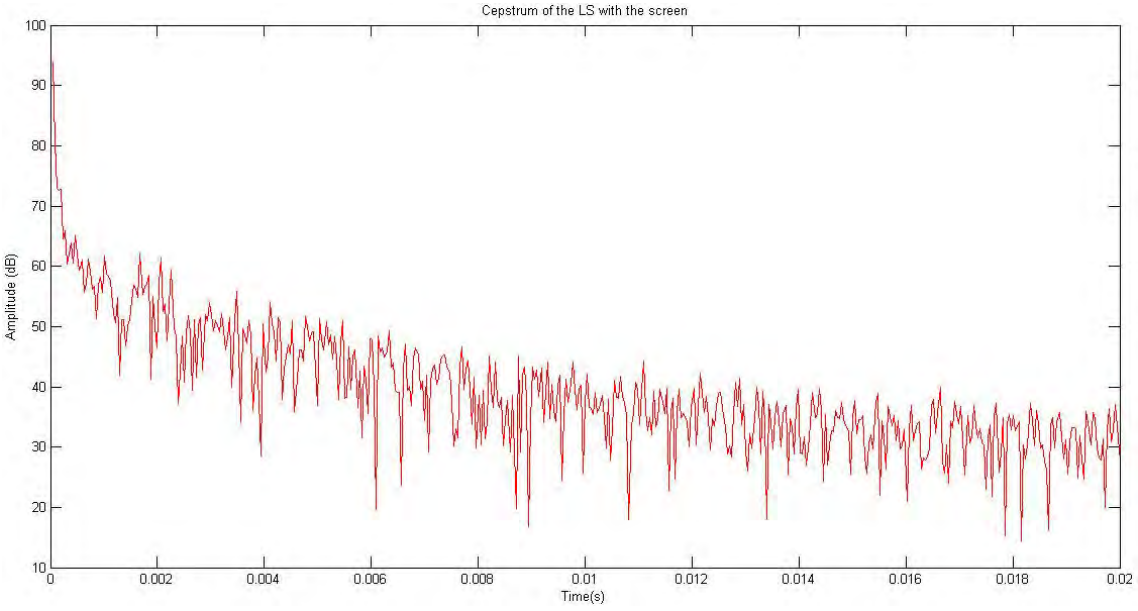

Fig. C. 42: Cepstrum analysis for Matt Plus MiniPerforated at a distance of 15 cm. 15 degrees

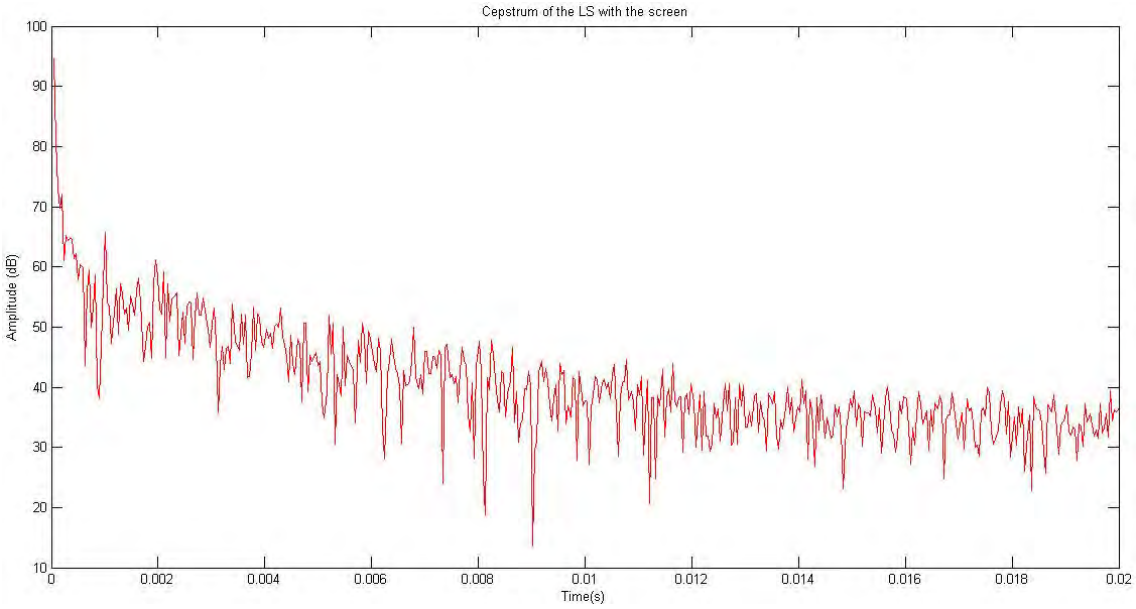

Fig. C. 43: Cepstrum analysis for Matt Plus MiniPerforated at a distance of 15 cm. 30 degrees

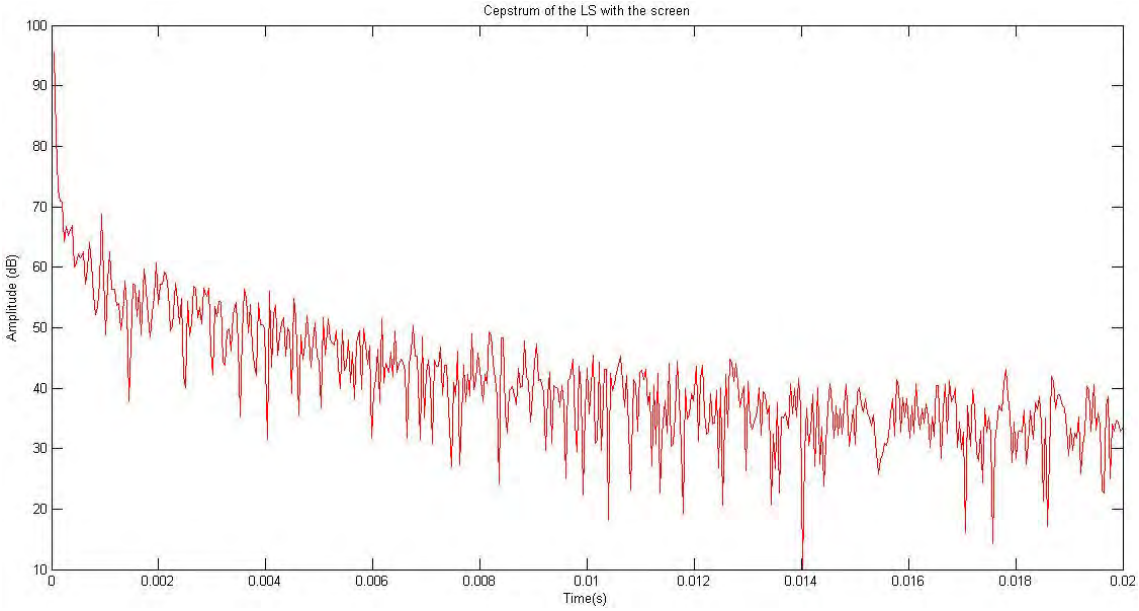

Fig. C. 44: Cepstrum analysis for Matt Plus MiniPerforated at a distance of 15 cm. 45 degrees

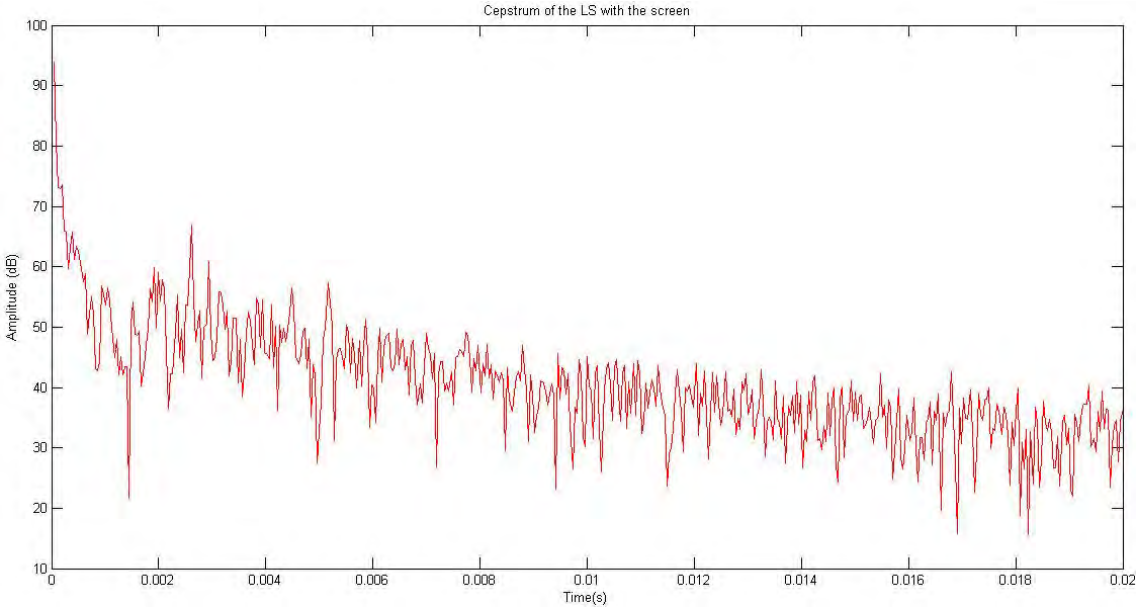

Fig. C. 45: Cepstrum analysis for Matt Plus MiniPerforated at a distance of 30 cm. 0 degrees

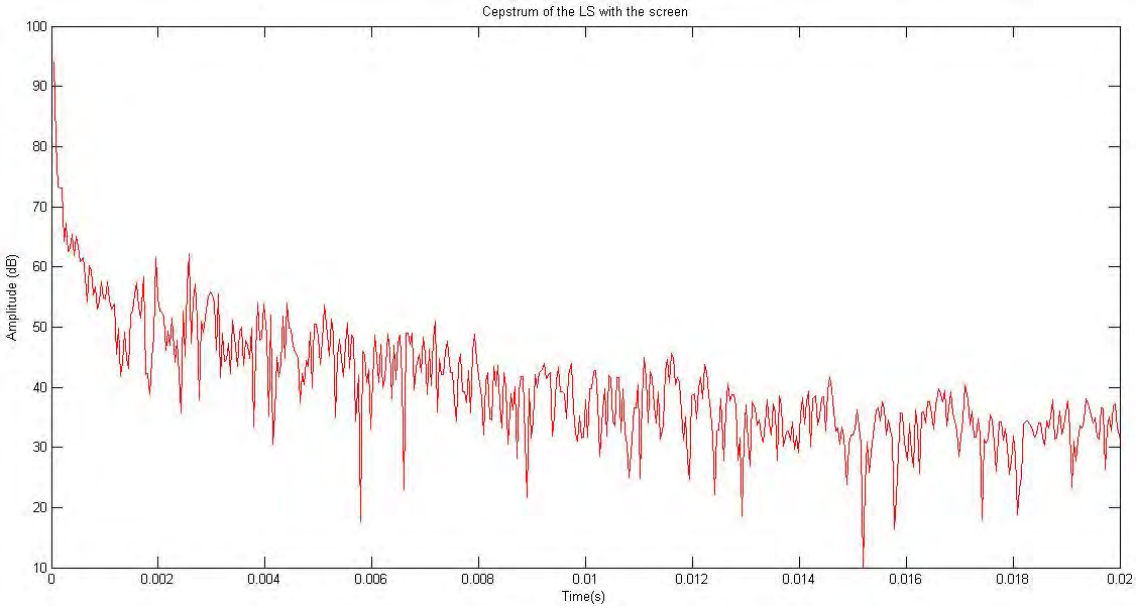

Fig. C. 46: Cepstrum analysis for Matt Plus MiniPerforated at a distance of 30 cm. 15 degrees

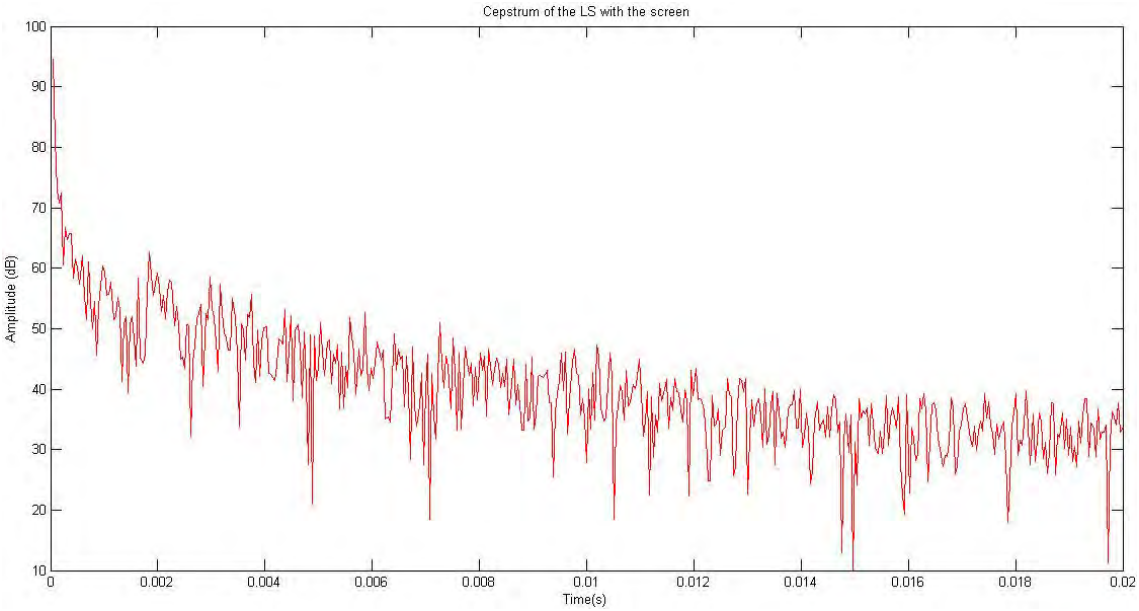

Fig. C. 47: Cepstrum analysis for Matt Plus MiniPerforated at a distance of 30 cm. 30 degrees

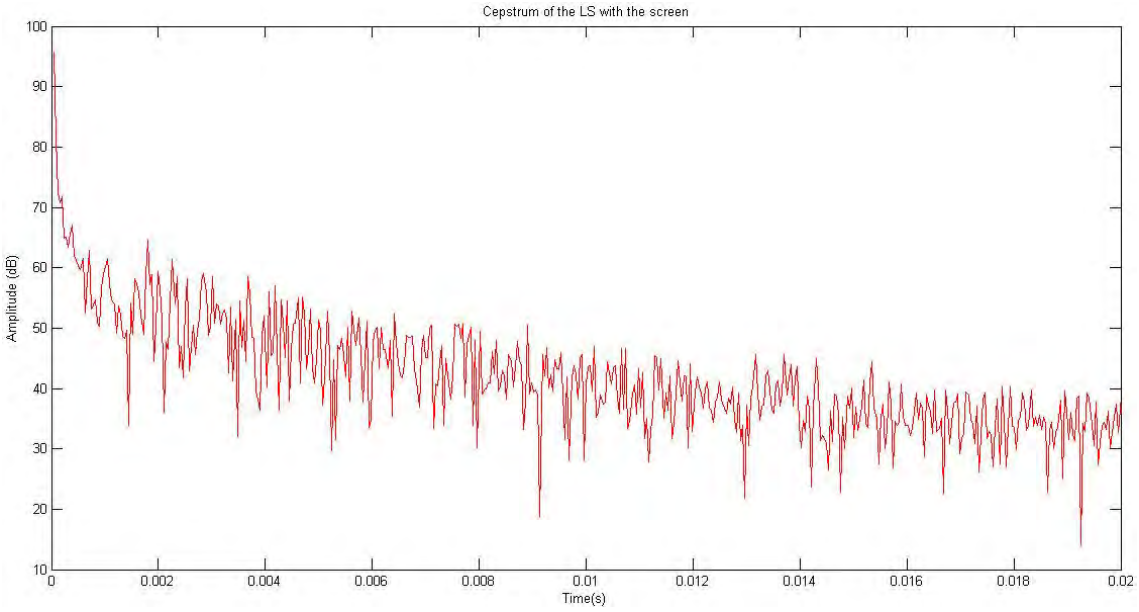

Fig. C. 48: Cepstrum analysis for Matt Plus MiniPerforated at a distance of 30 cm. 45 degrees

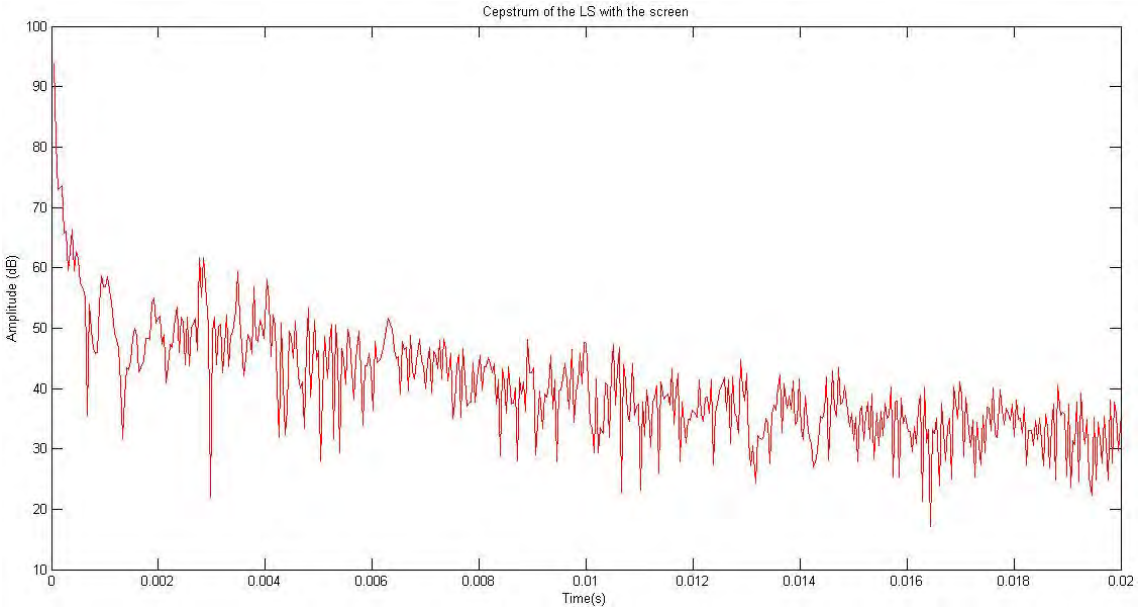

Fig. C. 49: Cepstrum analysis for Matt Plus MiniPerforated at a distance of 45 cm. 0 degrees

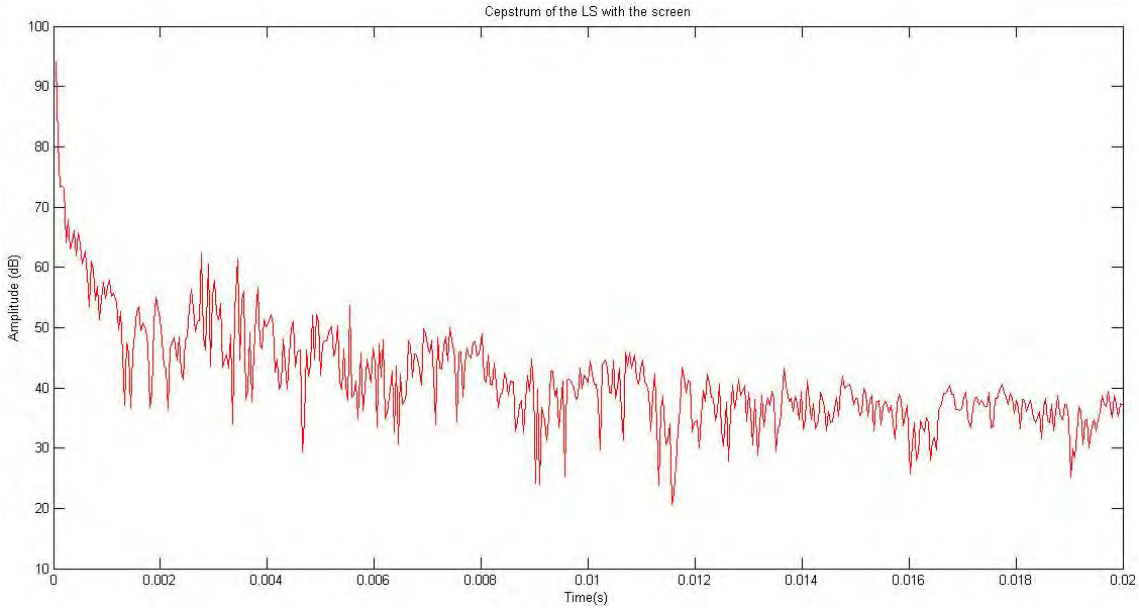

Fig. C. 50: Cepstrum analysis for Matt Plus MiniPerforated at a distance of 45 cm. 15 degrees

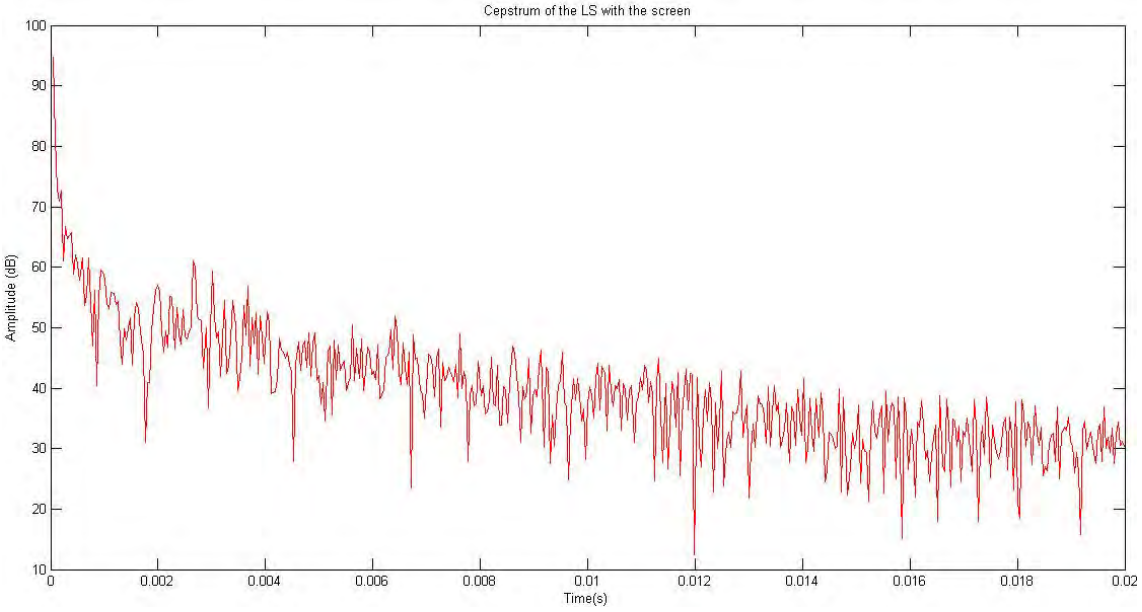

Fig. C. 51: Cepstrum analysis for Matt Plus MiniPerforated at a distance of 45 cm. 30 degrees

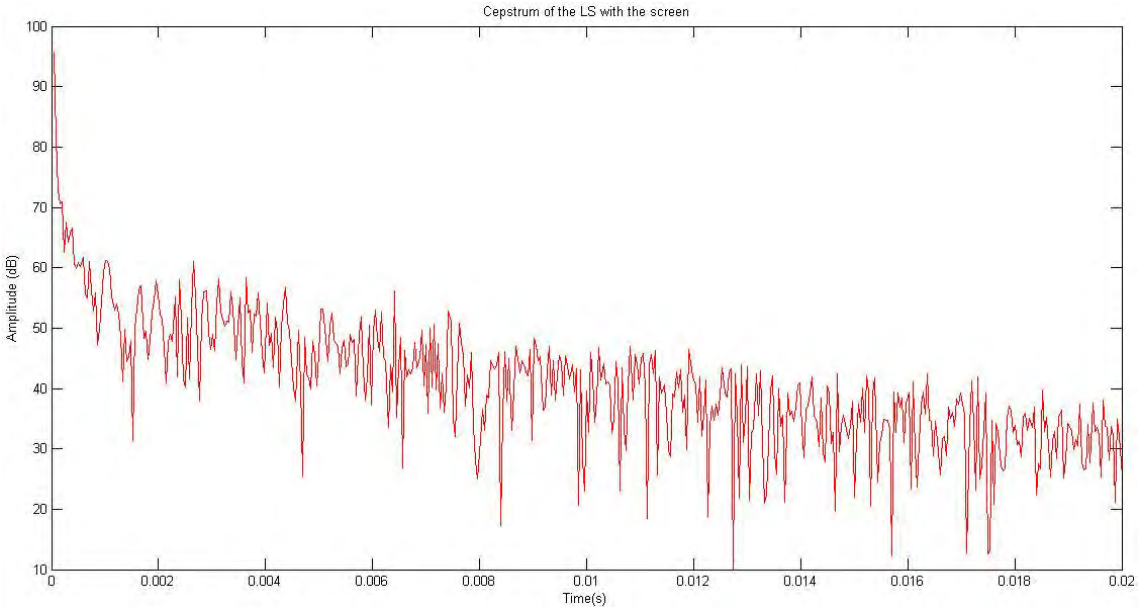

Fig. C. 52: Cepstrum analysis for Matt Plus MiniPerforated at a distance of 45 cm. 45 degrees

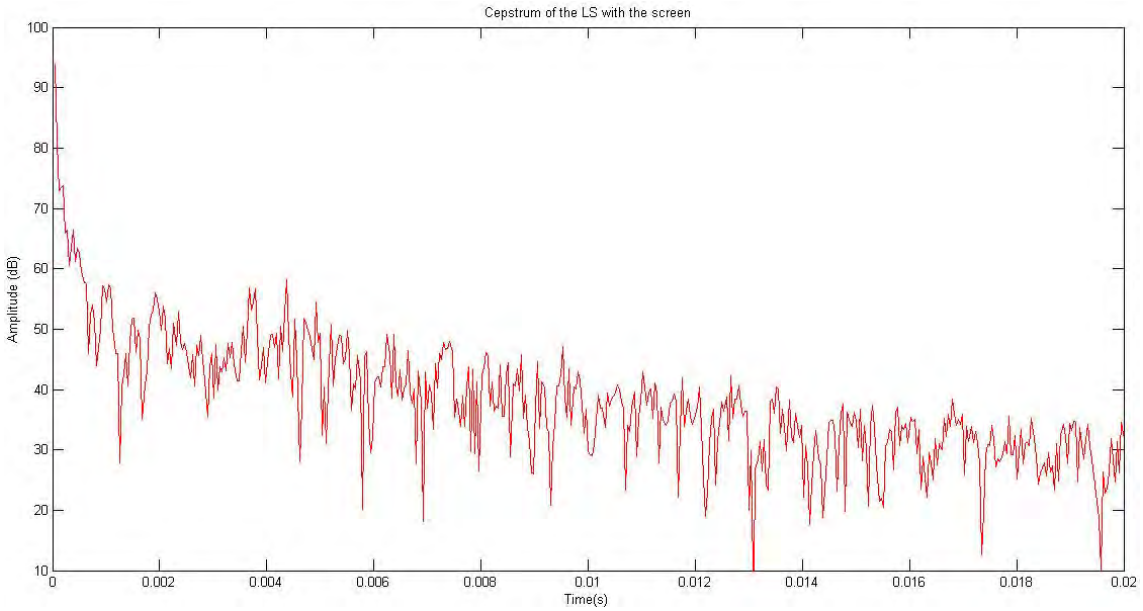

Fig. C. 53: Cepstrum analysis for Matt Plus MiniPerforated at a distance of 60 cm. 0 degrees

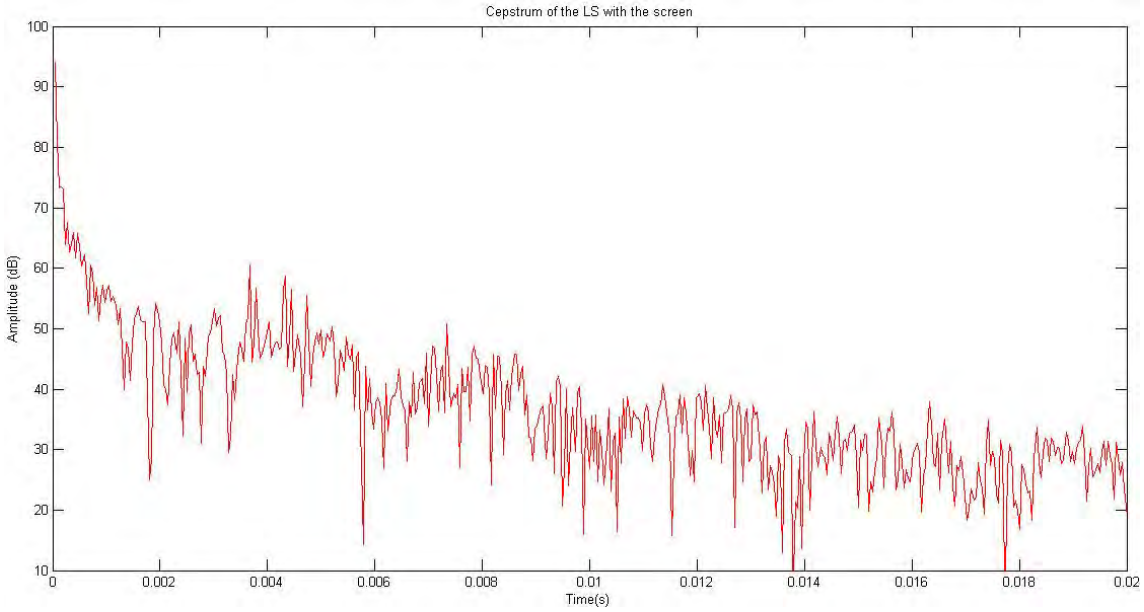

Fig. C. 54: Cepstrum analysis for Matt Plus MiniPerforated at a distance of 60 cm. 15 degrees

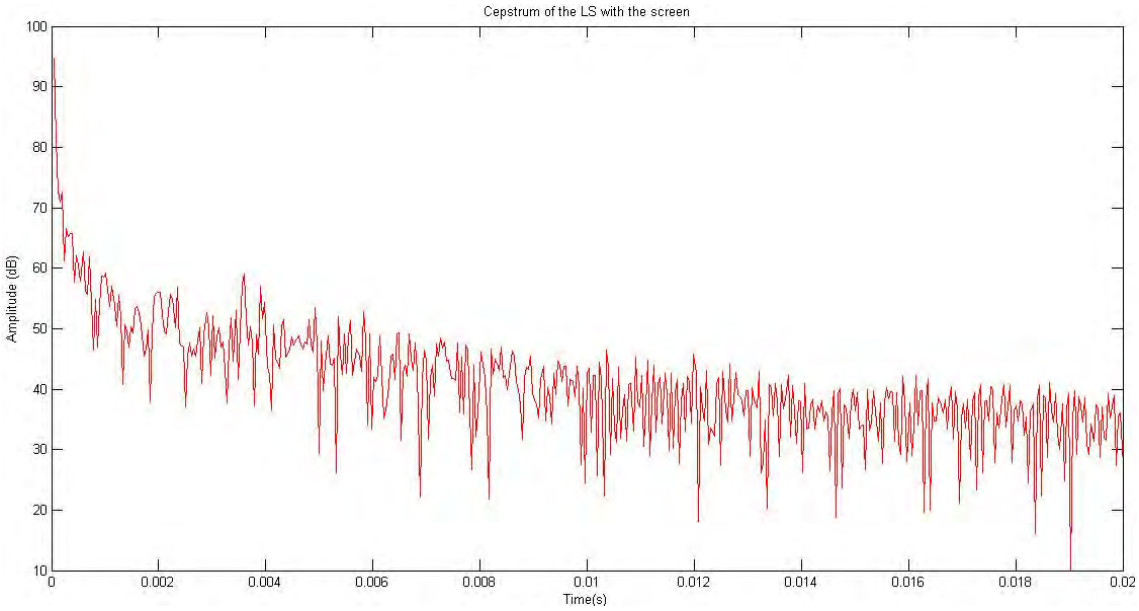

Fig. C. 55: Cepstrum analysis for Matt Plus MiniPerforated at a distance of 60 cm. 30 degrees

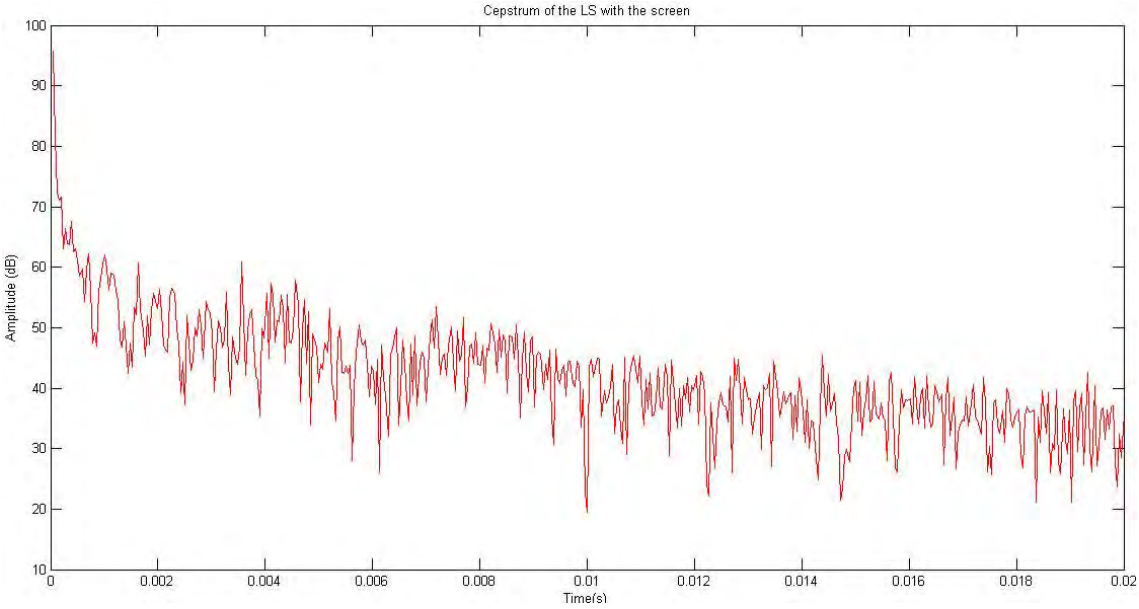

Fig. C. 56: Cepstrum analysis for Matt Plus MiniPerforated at a distance of 60 cm. 45 degrees

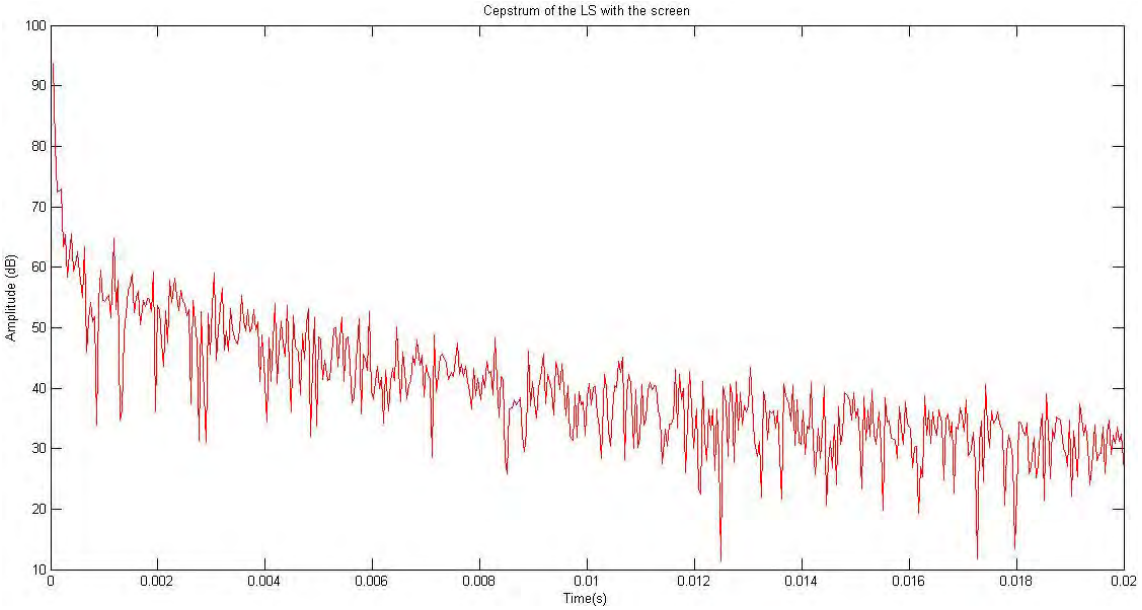

Fig. C. 57: Cepstrum analysis for Matt Plus MiniPerforated with screen angled 10 degrees. Mic position 0 deg

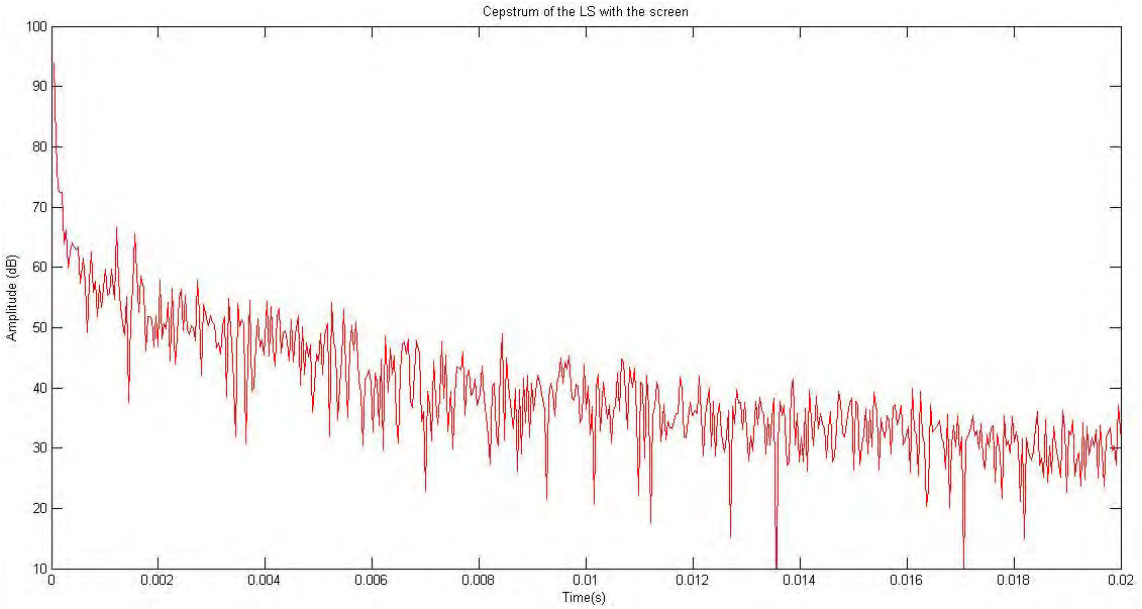

Fig. C. 58: Cepstrum analysis for Matt Plus MiniPerforated with screen angled 10 degrees. Mic position 15 deg

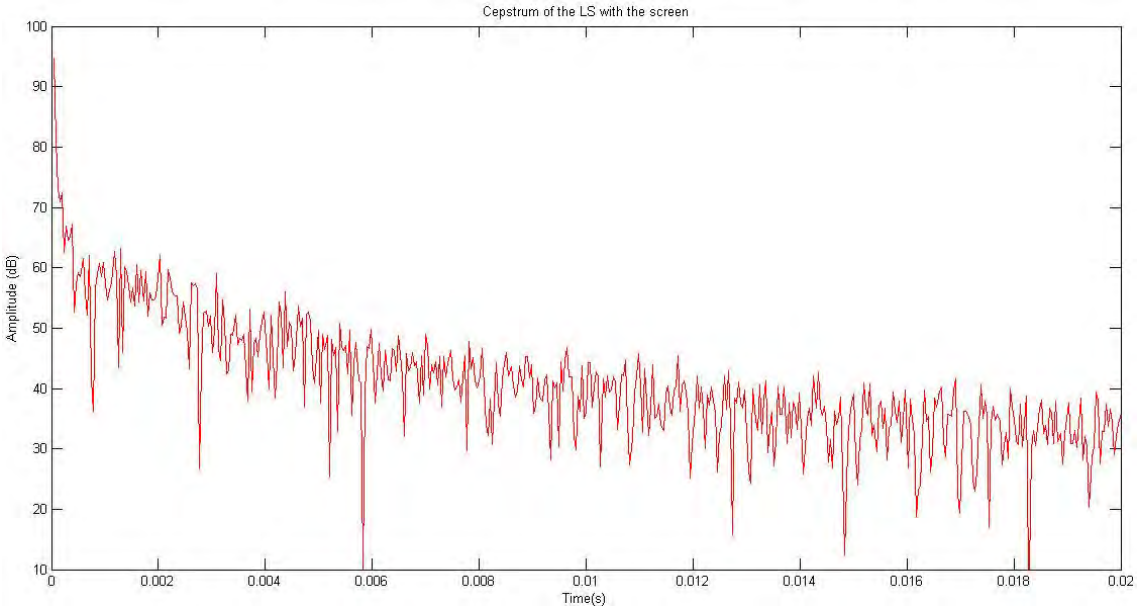

Fig. C. 59: Cepstrum analysis for Matt Plus MiniPerforated with screen angled 10 degrees. Mic position 30 deg

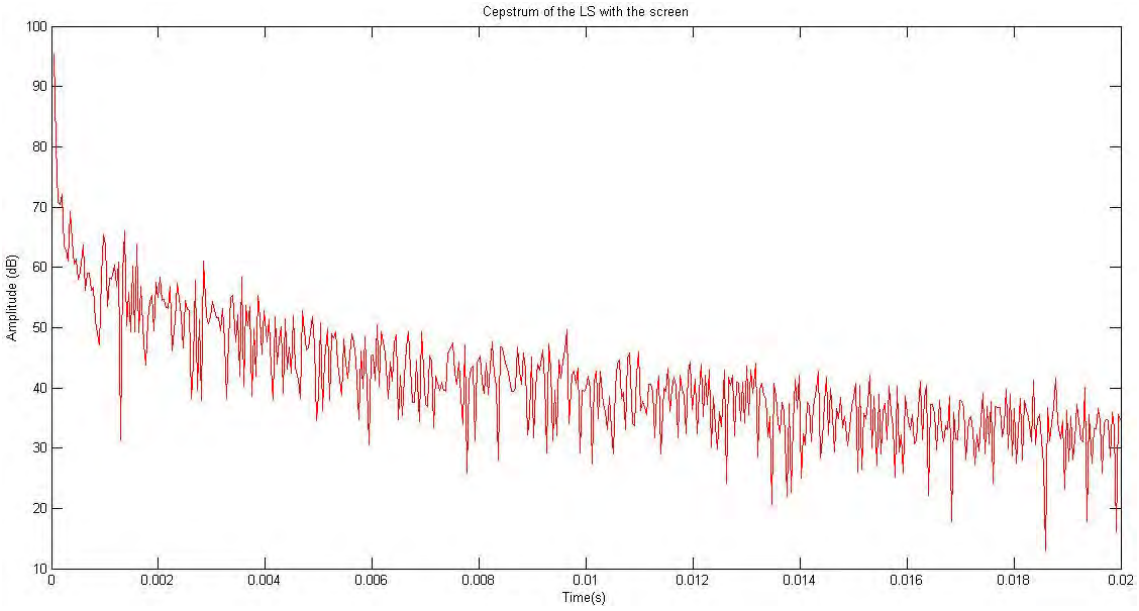

Fig. C. 60: Cepstrum analysis for Matt Plus MiniPerforated with screen angled 10 degrees. Mic position 45 deg

Cepstrum analysis for screen Matt Plus MiniPerforated with screen angled 25 deg

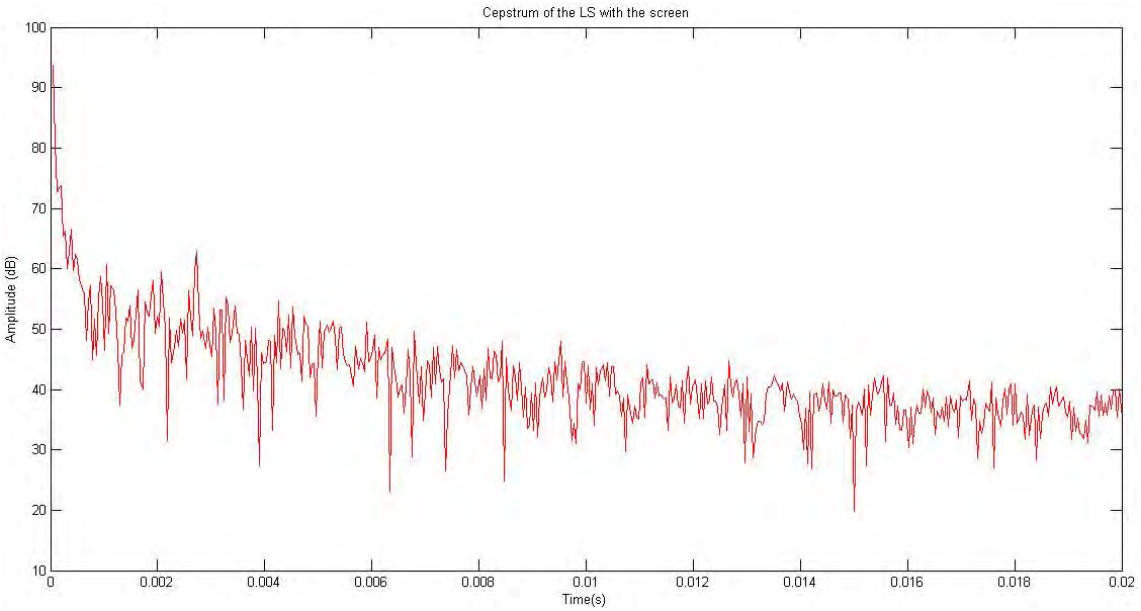

Fig. C. 61: Cepstrum analysis for Matt Plus MiniPerforated with screen angled 25 degrees. Mic position 0 deg

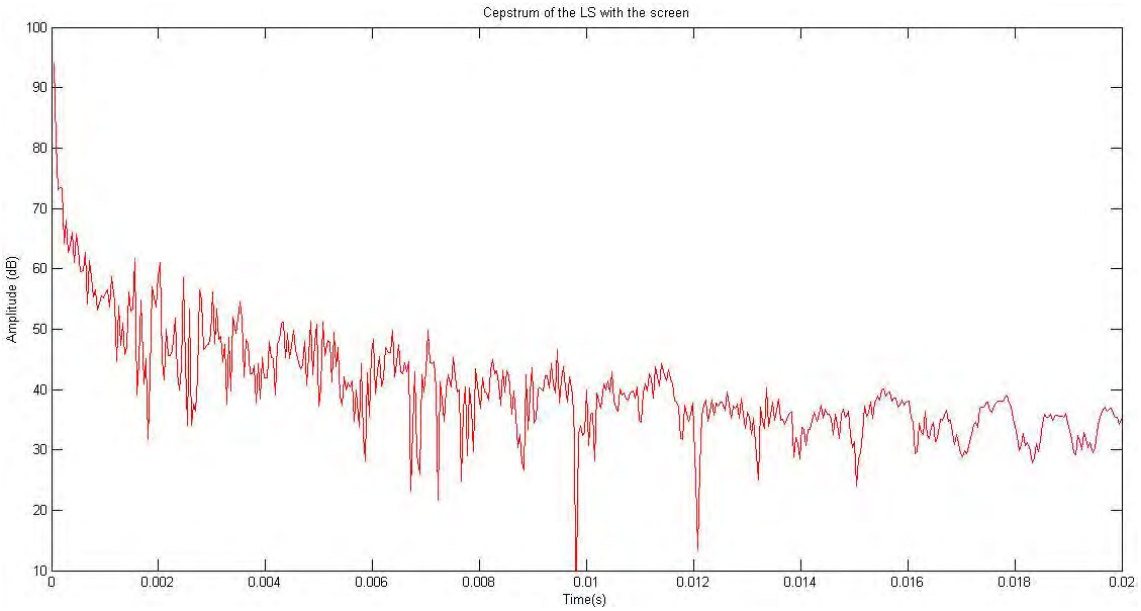

Fig. C. 62: Cepstrum analysis for Matt Plus MiniPerforated with screen angled 25 degrees. Mic position 15 deg

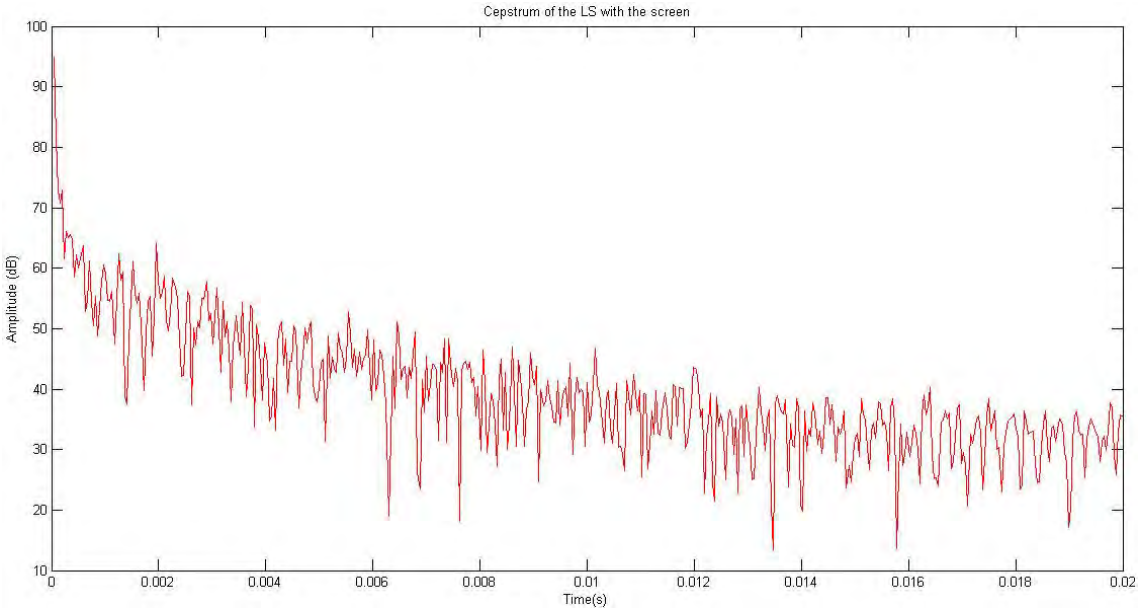

Fig. C. 63: Cepstrum analysis for Matt Plus MiniPerforated with screen angled 25 degrees. Mic position 30 deg

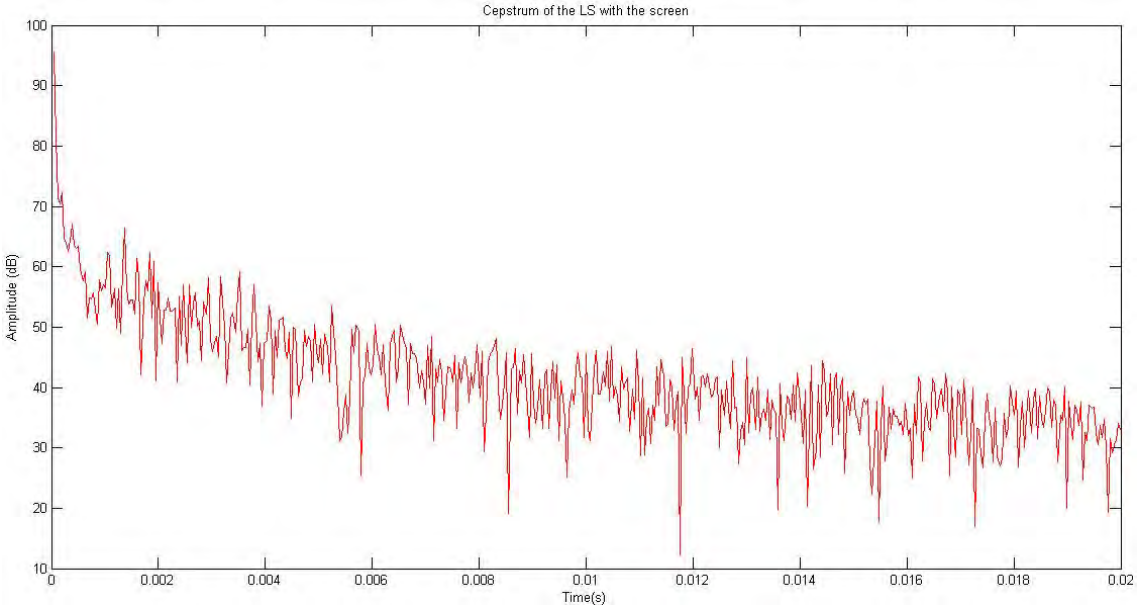

Fig. C. 64: Cepstrum analysis for Matt Plus MiniPerforated with screen angled 25 degrees. Mic position 45 deg

C. 3. ClearPix 2 White 1.0

Cepstrum analysis for screen ClearPix 2 White 1.0 at a distance of 2 cm

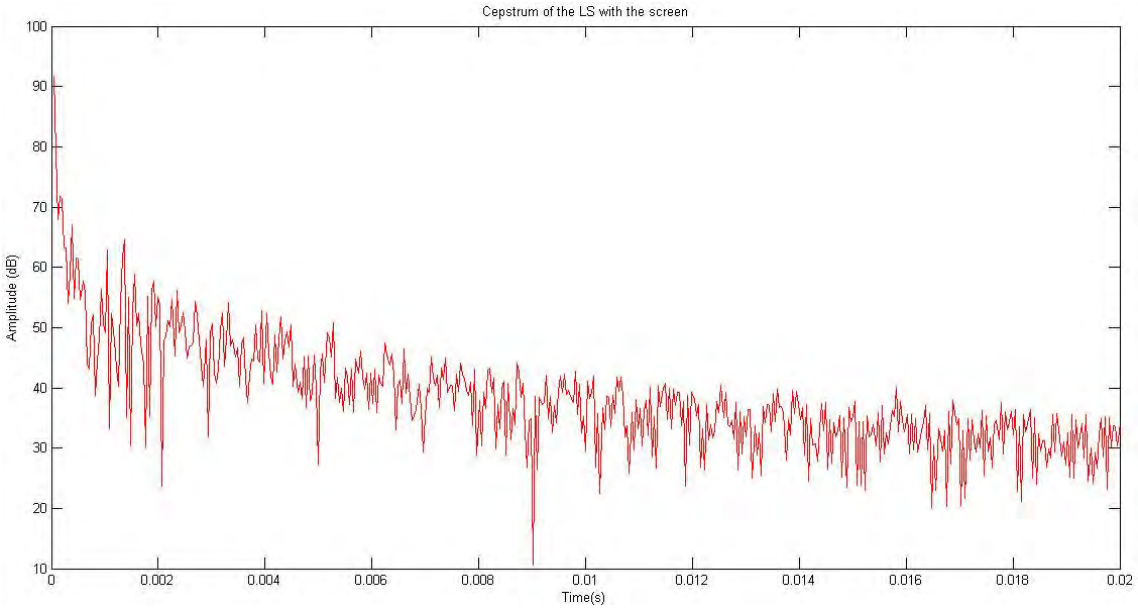

Fig. C. 65: Cepstrum analysis for ClearPix 2 White 1.0 at a distance of 2 cm. 0 degrees

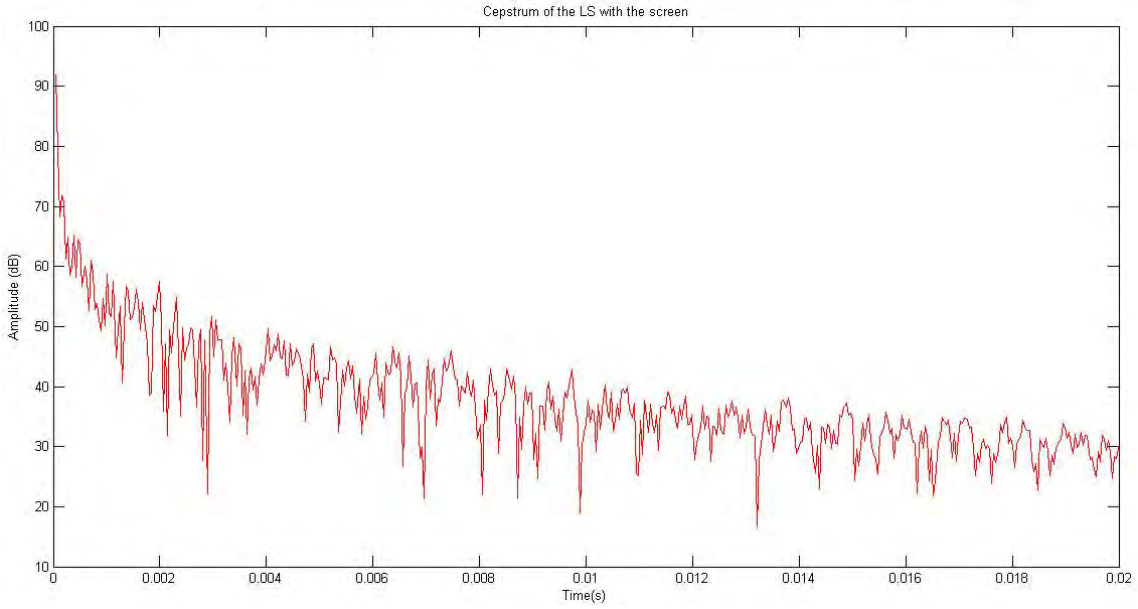

Fig. C. 66: Cepstrum analysis for ClearPix 2 White 1.0 at a distance of 2 cm. 15 degrees

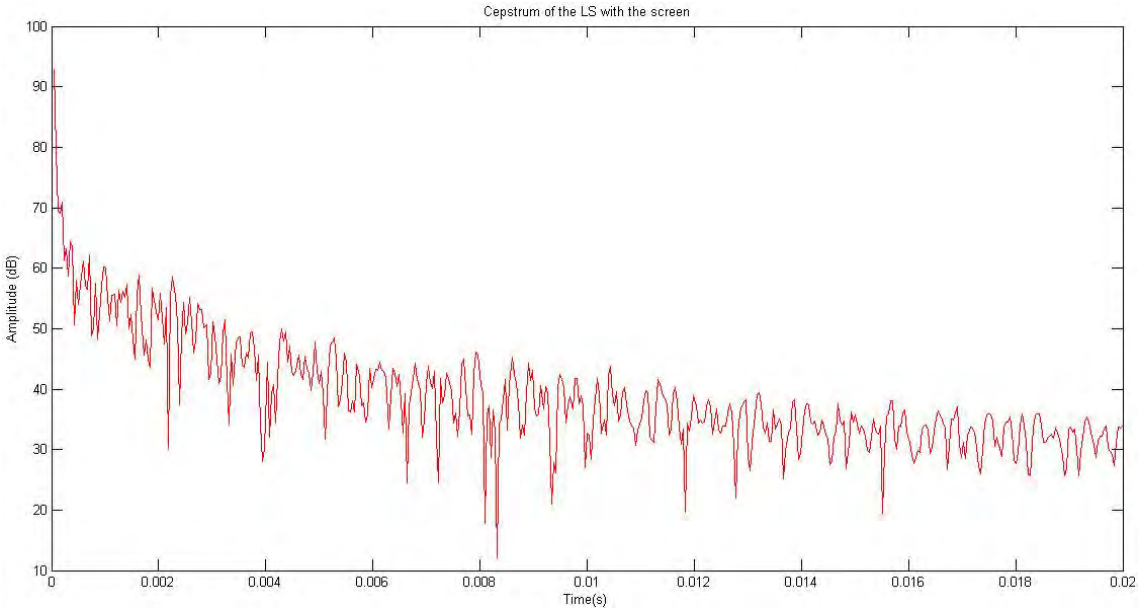

Fig. C. 67: Cepstrum analysis for ClearPix 2 White 1.0 at a distance of 2 cm. 30 degrees

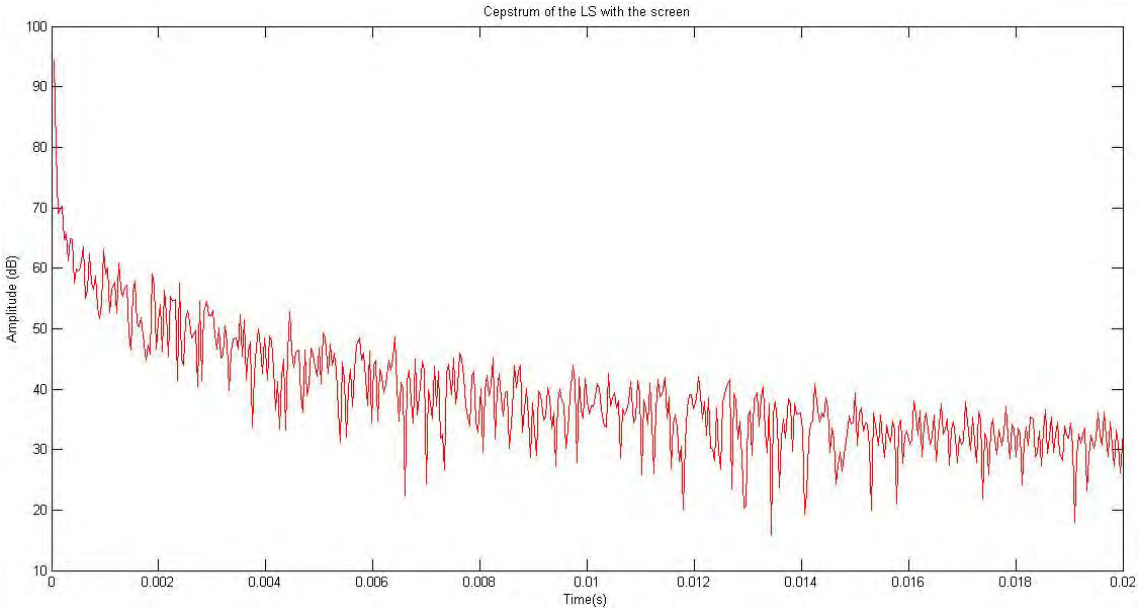

Fig. C. 68: Cepstrum analysis for ClearPix 2 White 1.0 at a distance of 2 cm. 45 degrees

Cepstrum analysis for screen ClearPix 2 White 1.0 at a distance of 7 cm

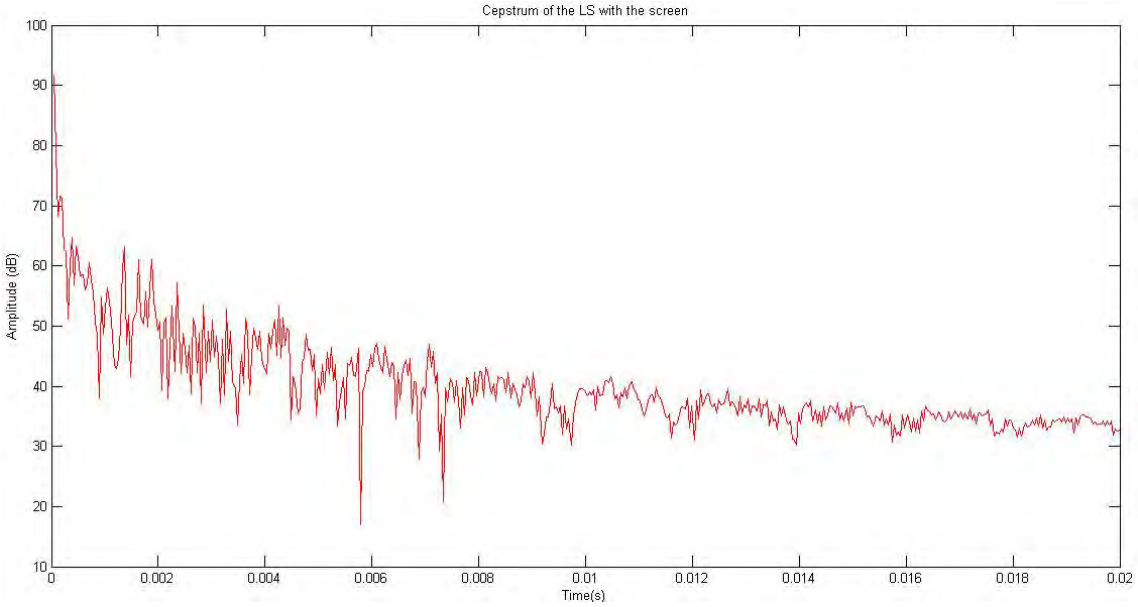

Fig. C. 69: Cepstrum analysis for ClearPix 2 White 1.0 at a distance of 7 cm. 0 degrees

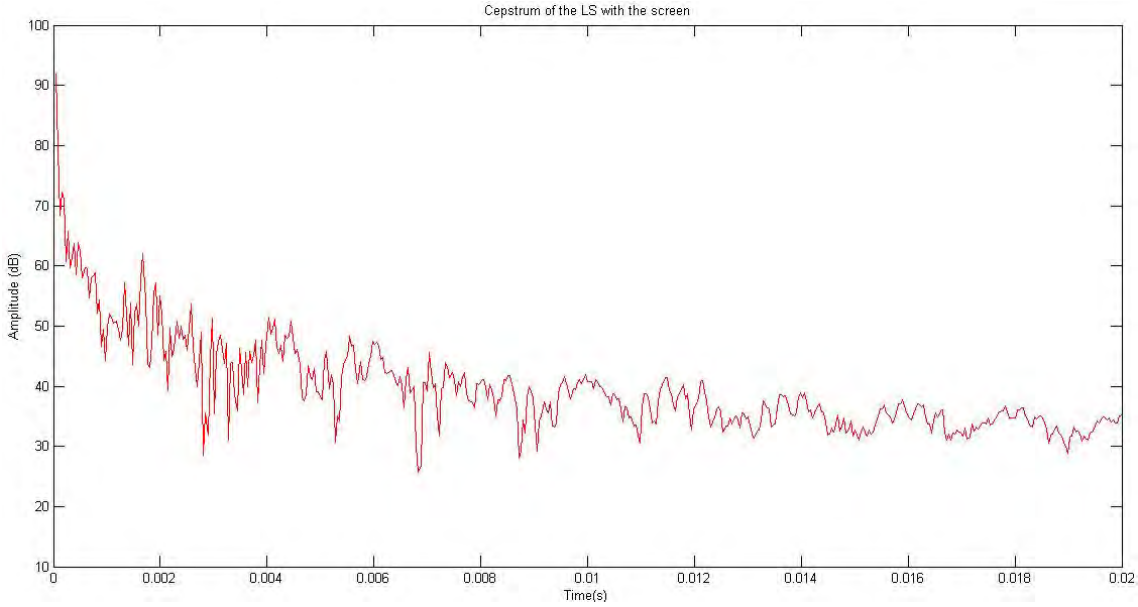

Fig. C. 70: Cepstrum analysis for ClearPix 2 White 1.0 at a distance of 7 cm. 15 degrees

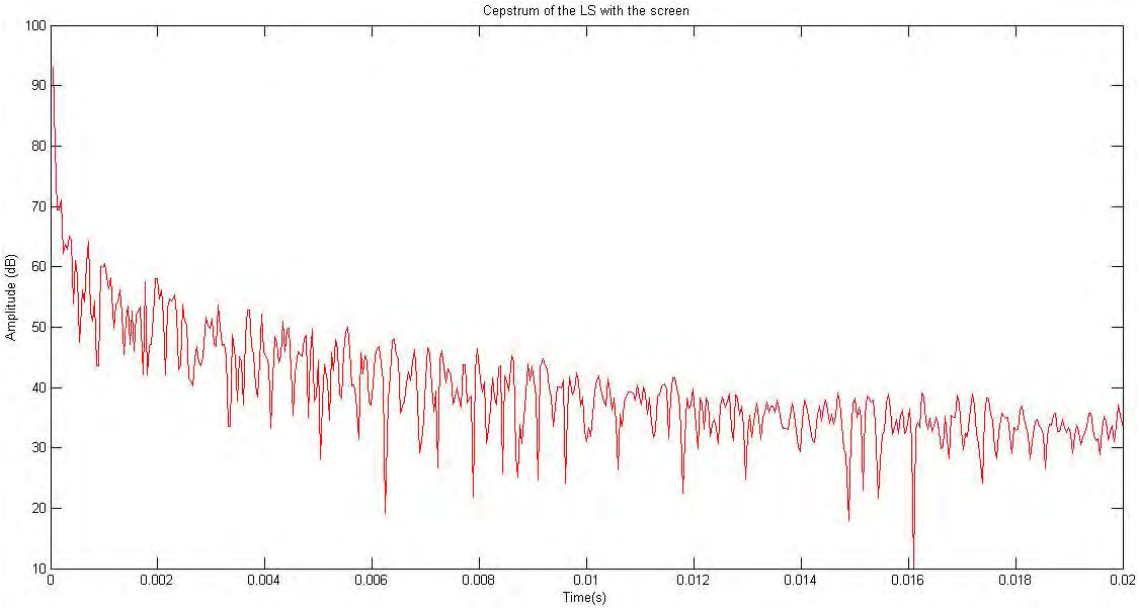

Fig. C. 71: Cepstrum analysis for ClearPix 2 White 1.0 at a distance of 7 cm. 30 degrees

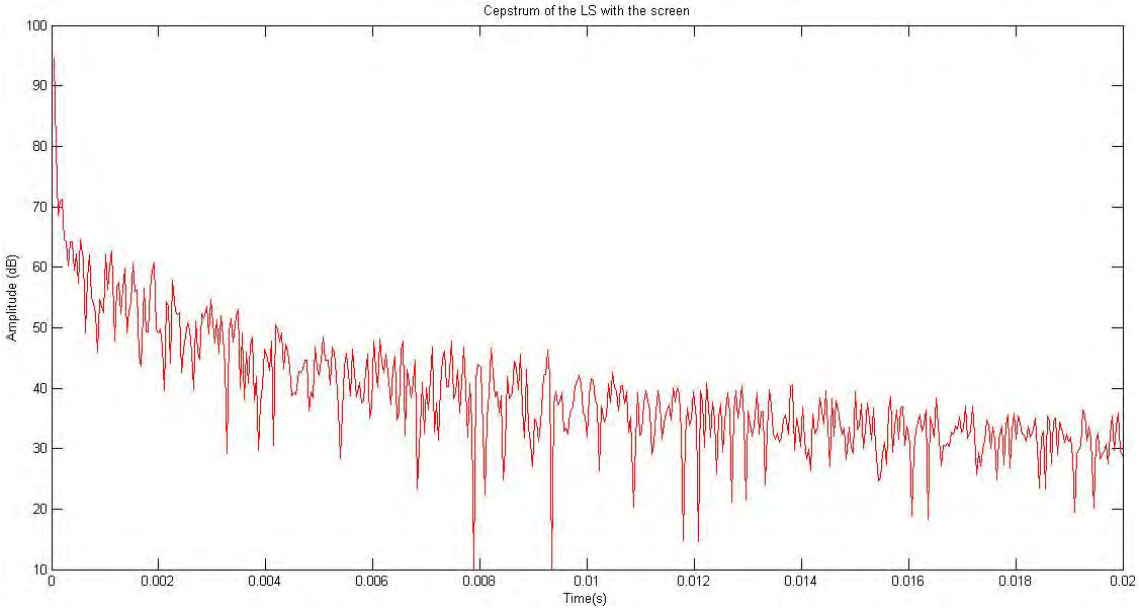

Fig. C. 72: Cepstrum analysis for ClearPix 2 White 1.0 at a distance of 7 cm. 45 degrees

Cepstrum analysis for screen ClearPix 2 White 1.0 at a distance of 15 cm

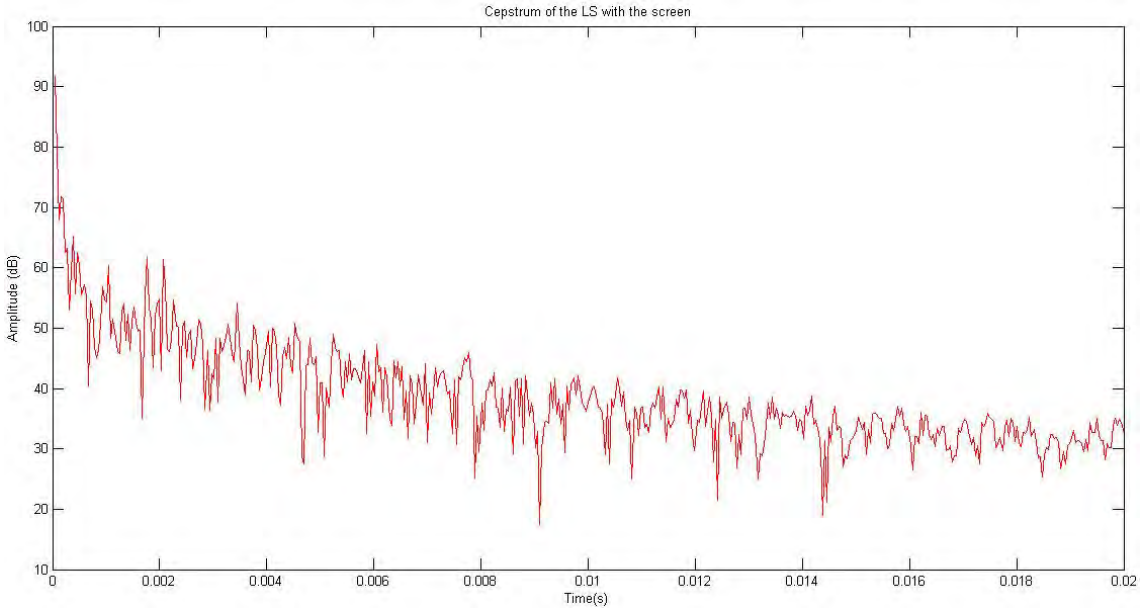

Fig. C. 73: Cepstrum analysis for ClearPix 2 White 1.0 at a distance of 15 cm. 0 degrees

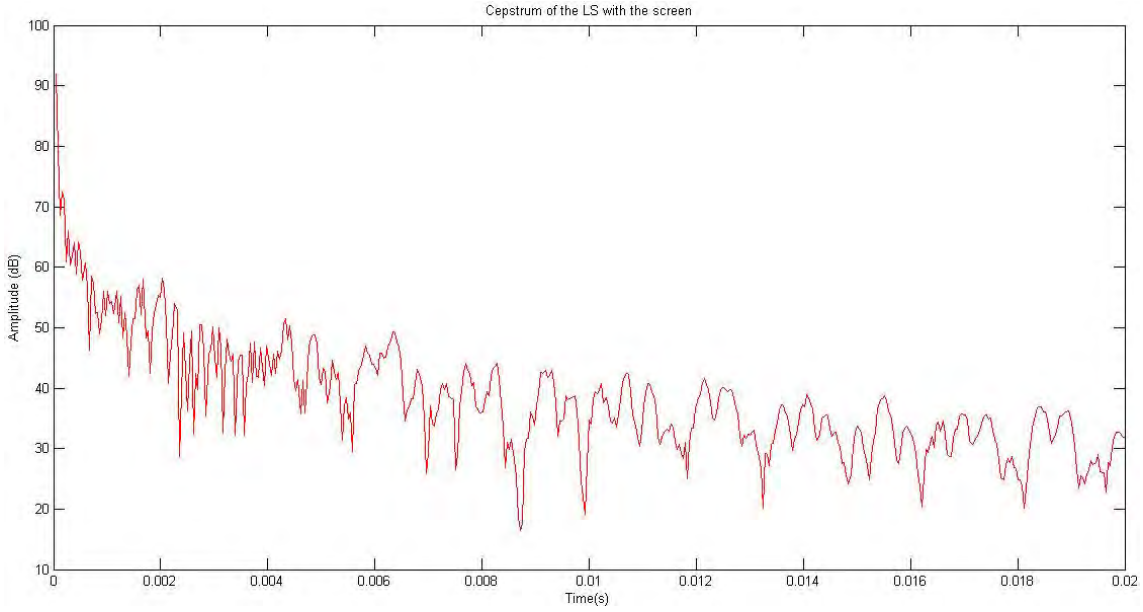

Fig. C. 74: Cepstrum analysis for ClearPix 2 White 1.0 at a distance of 15 cm. 15 degrees

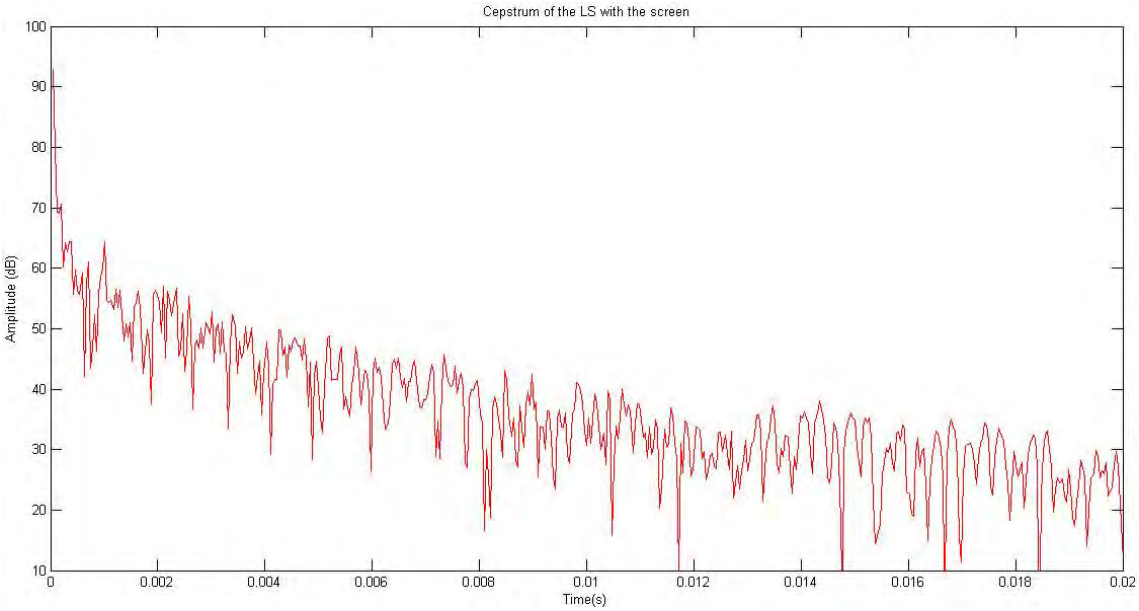

Fig. C. 75: Cepstrum analysis for ClearPix 2 White 1.0 at a distance of 15 cm. 30 degrees

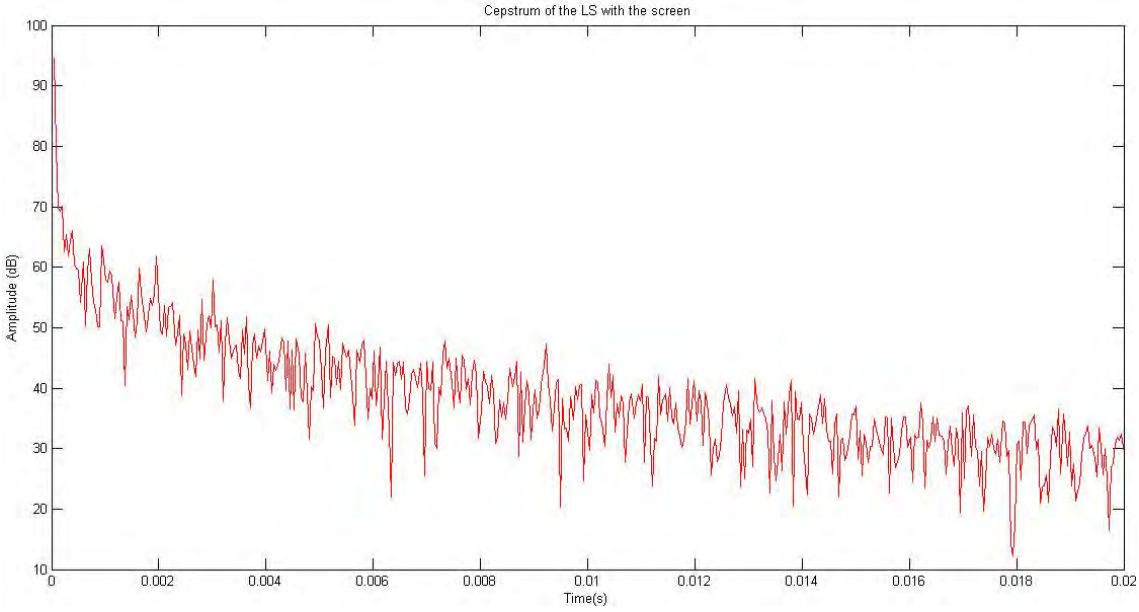

Fig. C. 76: Cepstrum analysis for ClearPix 2 White 1.0 at a distance of 15 cm. 45 degrees

Cepstrum analysis for screen ClearPix 2 White 1.0 at a distance of 30 cm

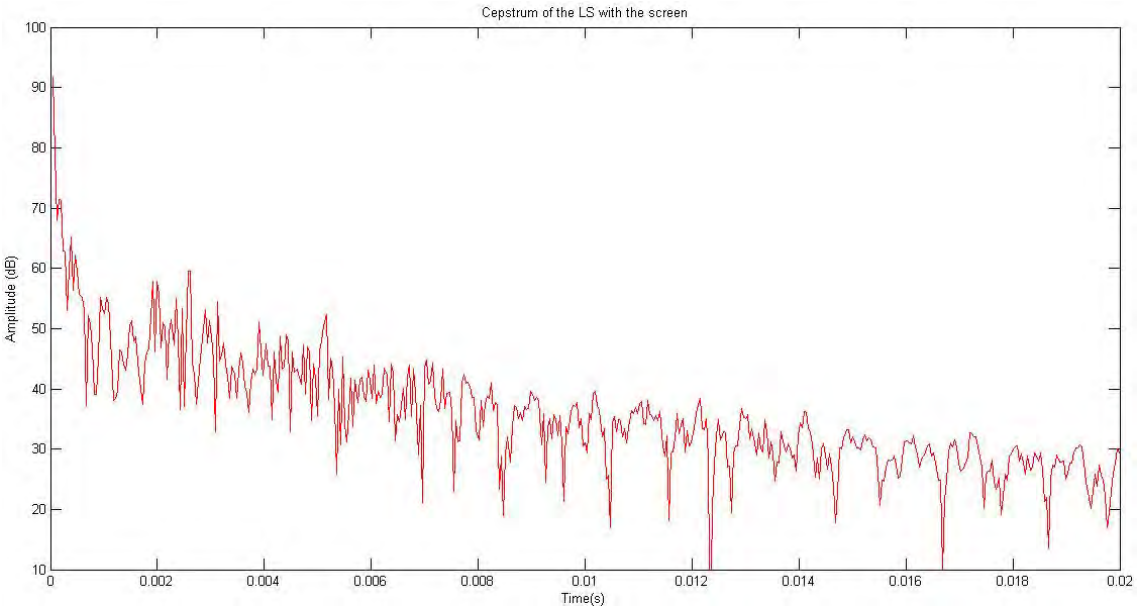

Fig. C. 77: Cepstrum analysis for ClearPix 2 White 1.0 at a distance of 30 cm. 0 degrees

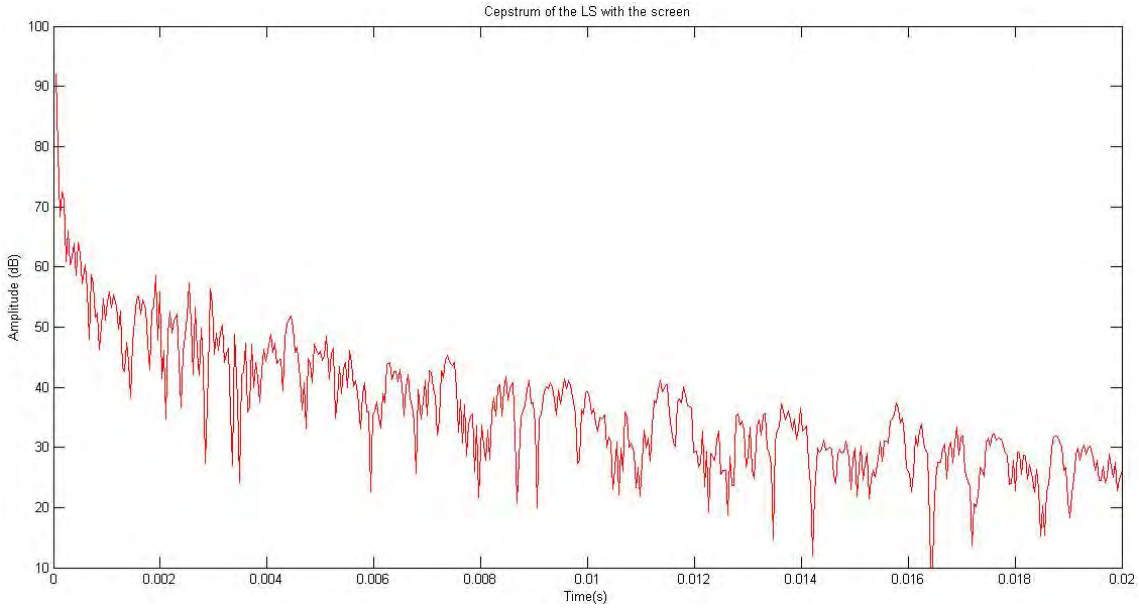

Fig. C. 78: Cepstrum analysis for ClearPix 2 White 1.0 at a distance of 30 cm. 15 degrees

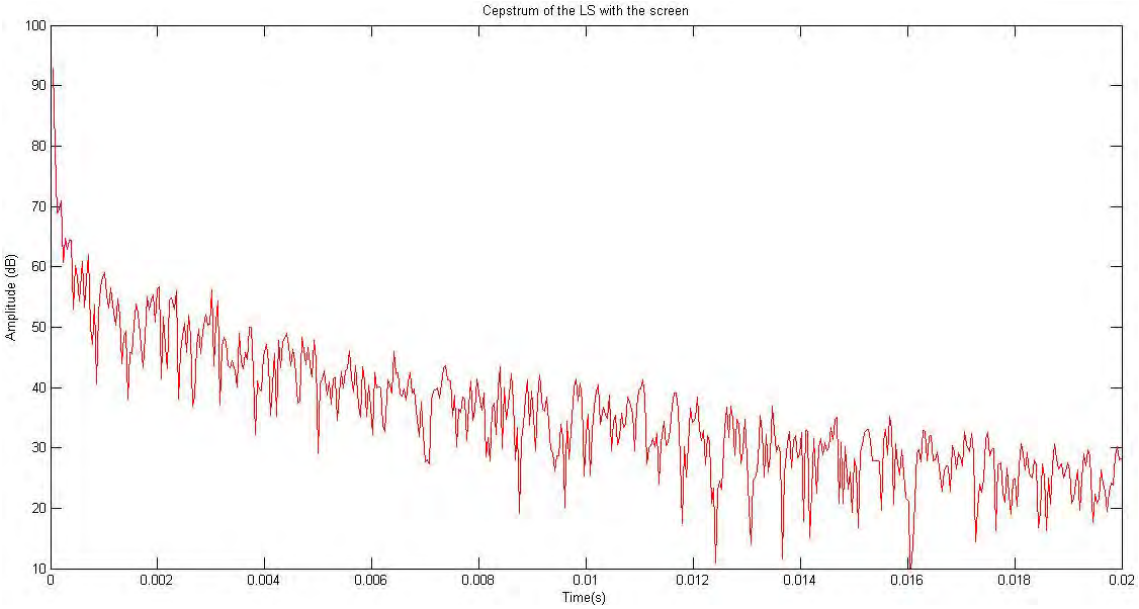

Fig. C. 79: Cepstrum analysis for ClearPix 2 White 1.0 at a distance of 30 cm. 30 degrees

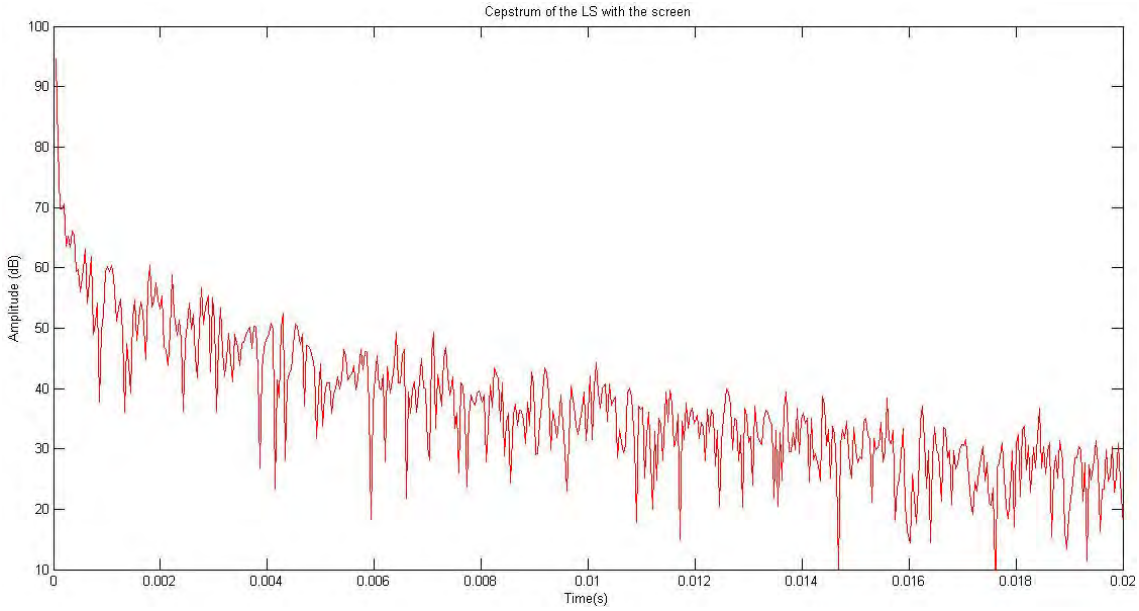

Fig. C. 80: Cepstrum analysis for ClearPix 2 White 1.0 at a distance of 30 cm. 45 degrees

Cepstrum analysis for screen ClearPix 2 White 1.0 at a distance of 45 cm

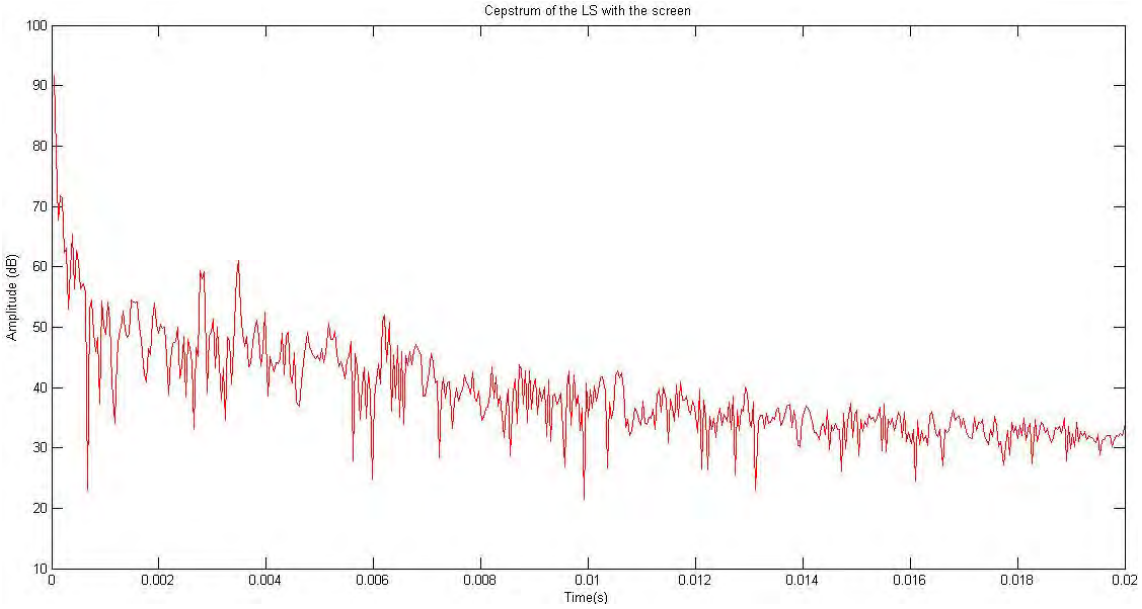

Fig. C. 81: Cepstrum analysis for ClearPix 2 White 1.0 at a distance of 45 cm. 0 degrees

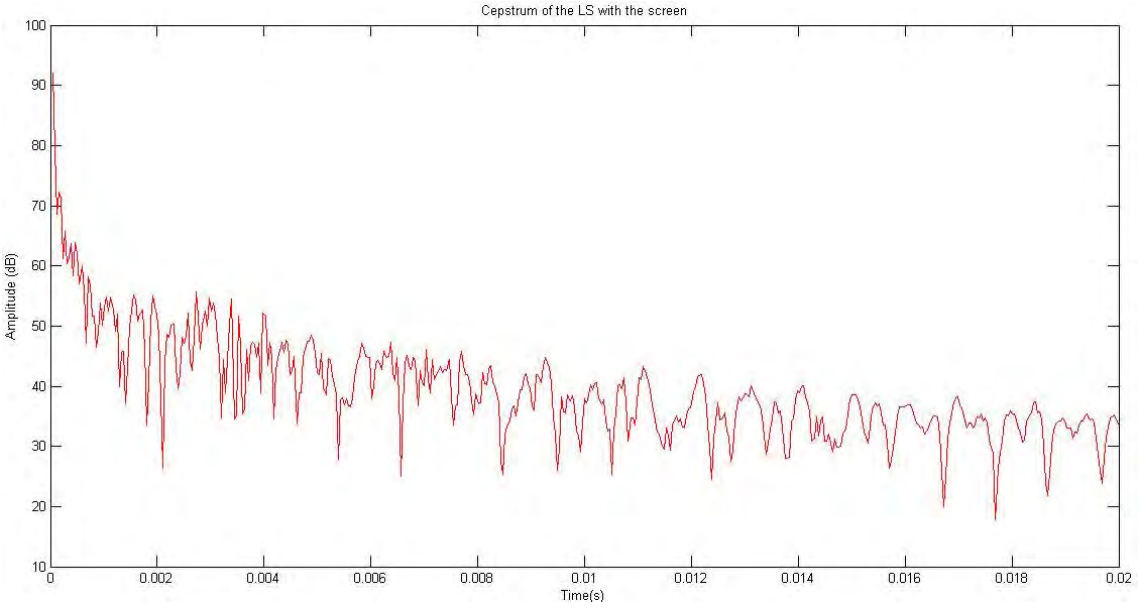

Fig. C. 82: Cepstrum analysis for ClearPix 2 White 1.0 at a distance of 45 cm. 15 degrees

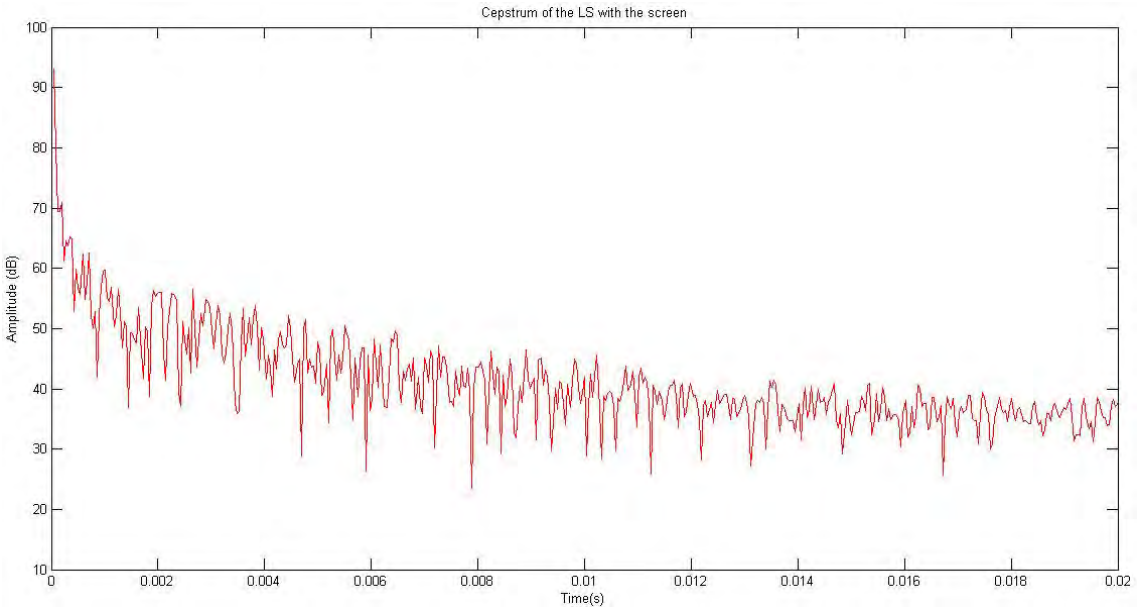

Fig. C. 83: Cepstrum analysis for ClearPix 2 White 1.0 at a distance of 45 cm. 30 degrees

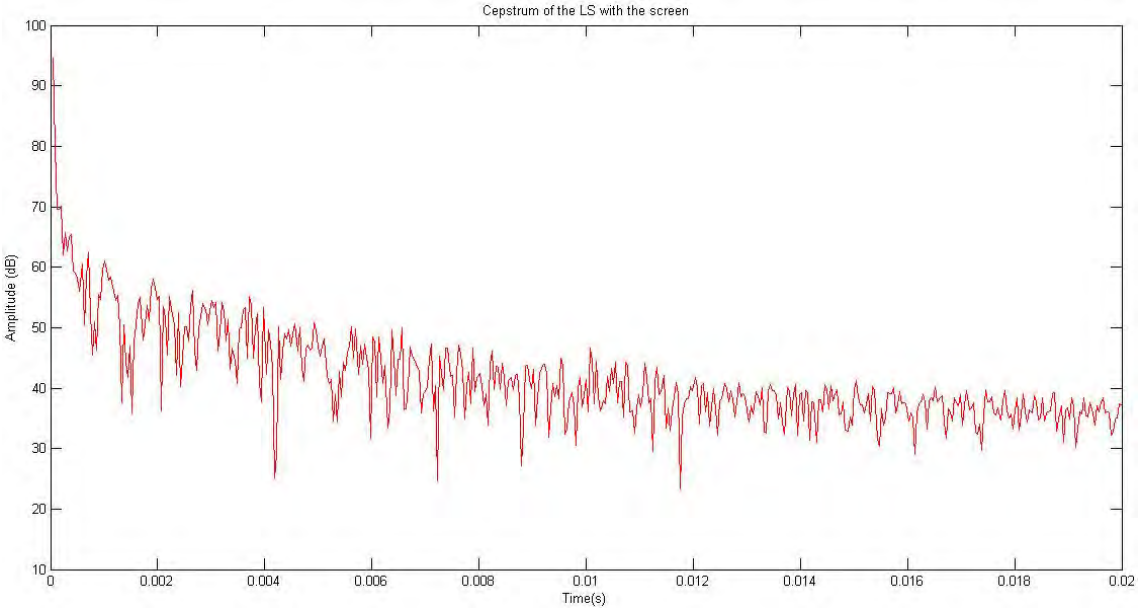

Fig. C. 84: Cepstrum analysis for ClearPix 2 White 1.0 at a distance of 45 cm. 45 degrees

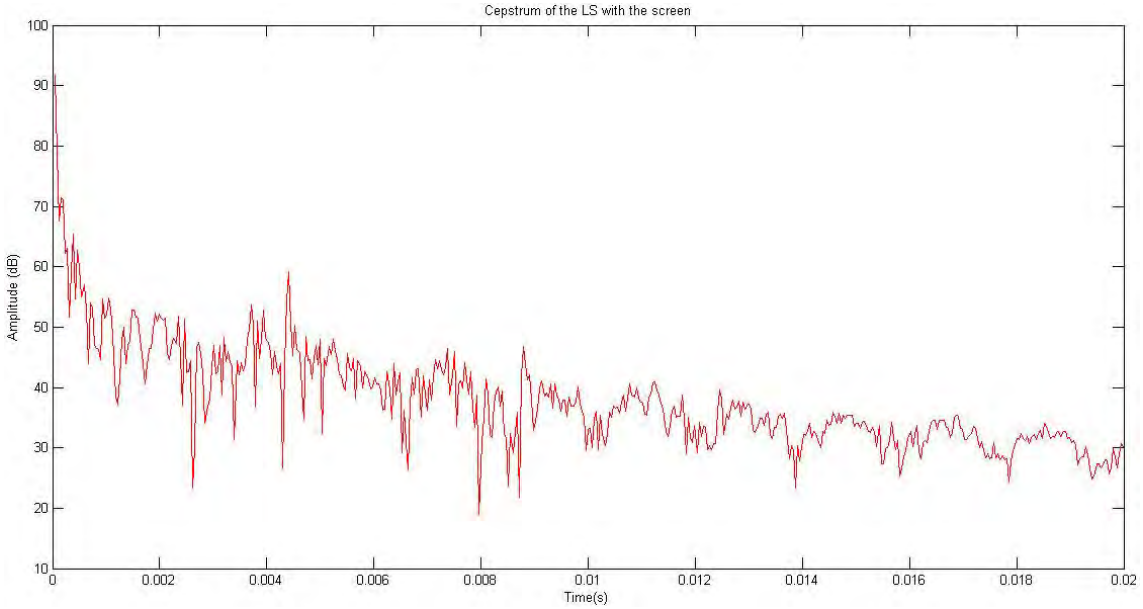

Fig. C. 85: Cepstrum analysis for ClearPix 2 White 1.0 at a distance of 60 cm. 0 degrees

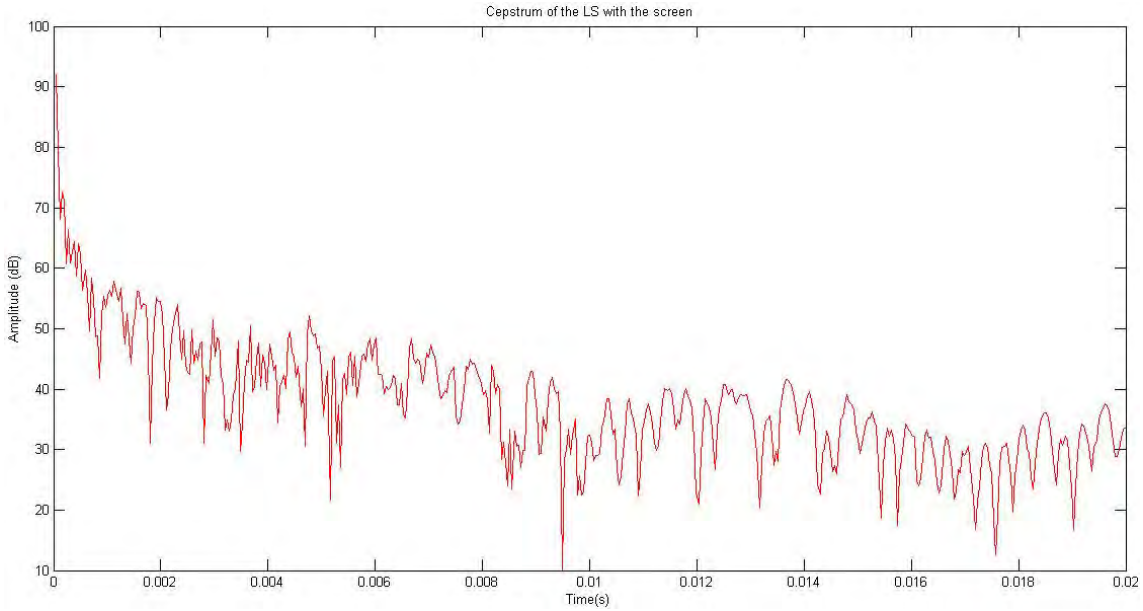

Fig. C. 86: Cepstrum analysis for ClearPix 2 White 1.0 at a distance of 60 cm. 15 degrees

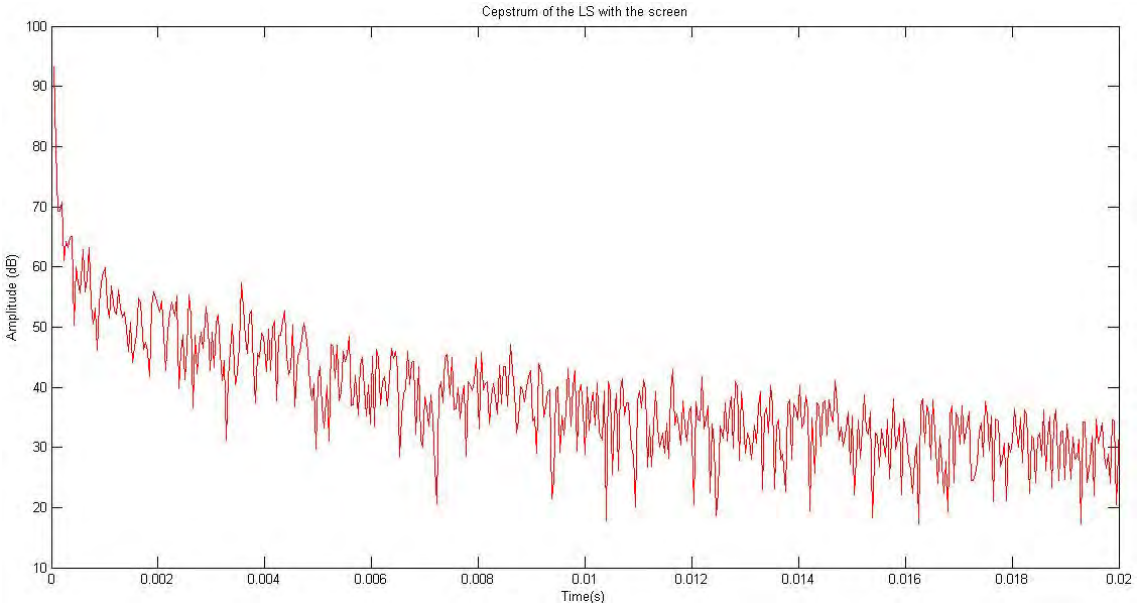

Fig. C. 87: Cepstrum analysis for ClearPix 2 White 1.0 at a distance of 60 cm. 30 degrees

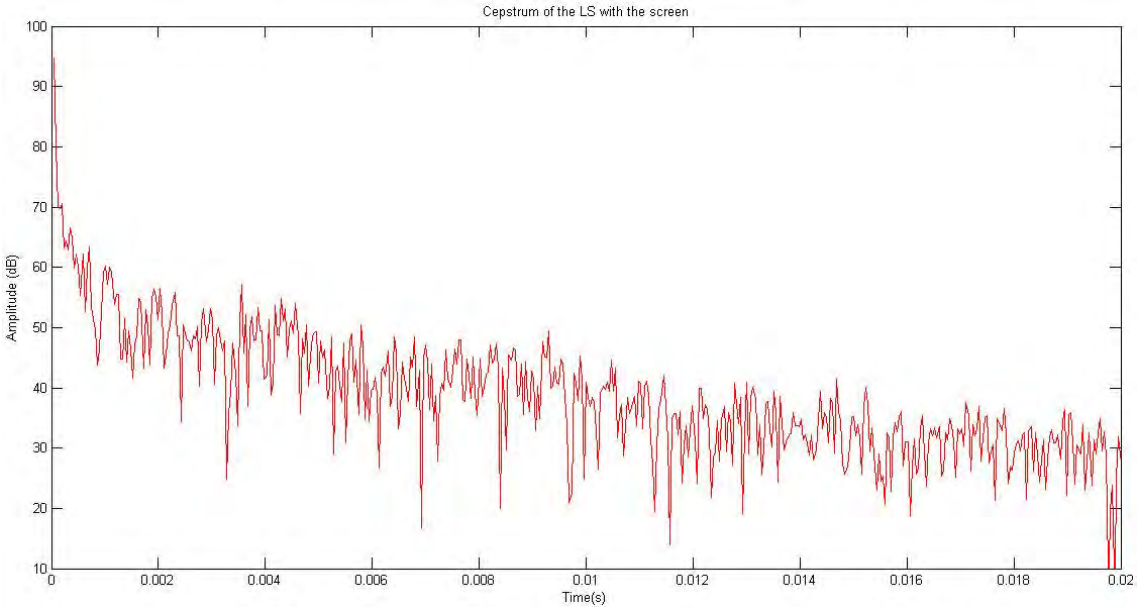

Fig. C. 88: Cepstrum analysis for ClearPix 2 White 1.0 at a distance of 60 cm. 45 degrees

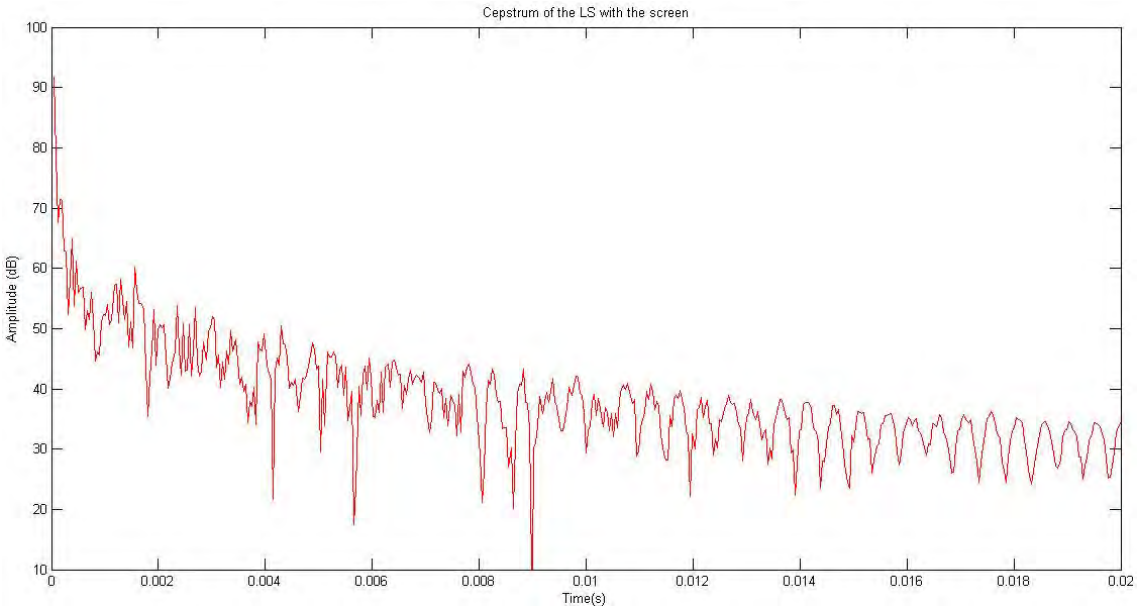

Fig. C. 89: Cepstrum analysis for ClearPix 2 White 1.0 with screen angled 10 degrees. Mic position 0 deg

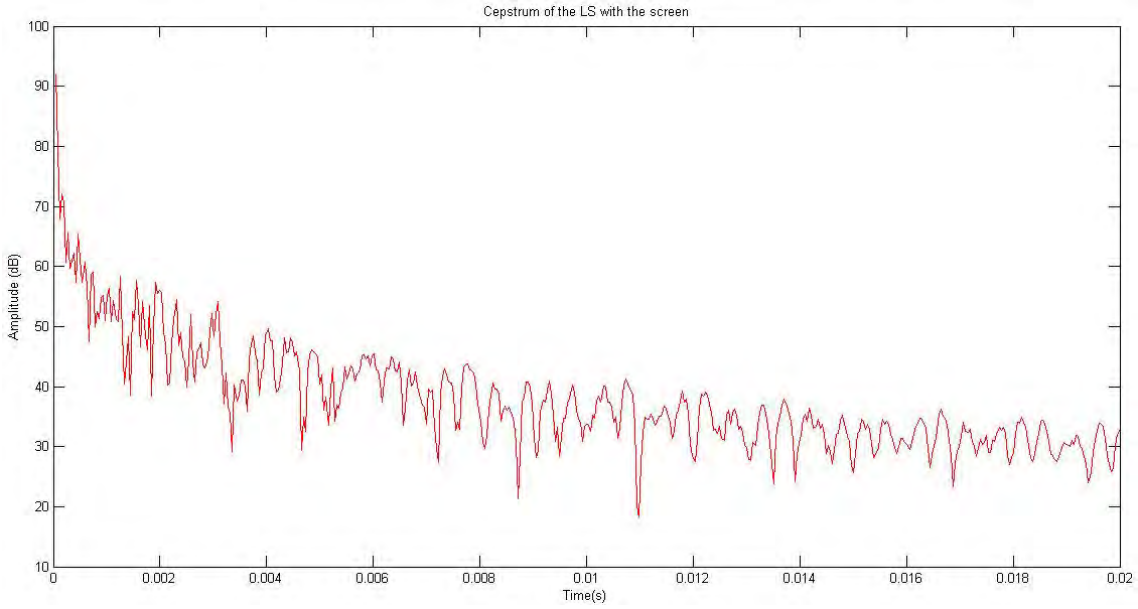

Fig. C. 90: Cepstrum analysis for ClearPix 2 White 1.0 with screen angled 10 degrees. Mic position 15 deg

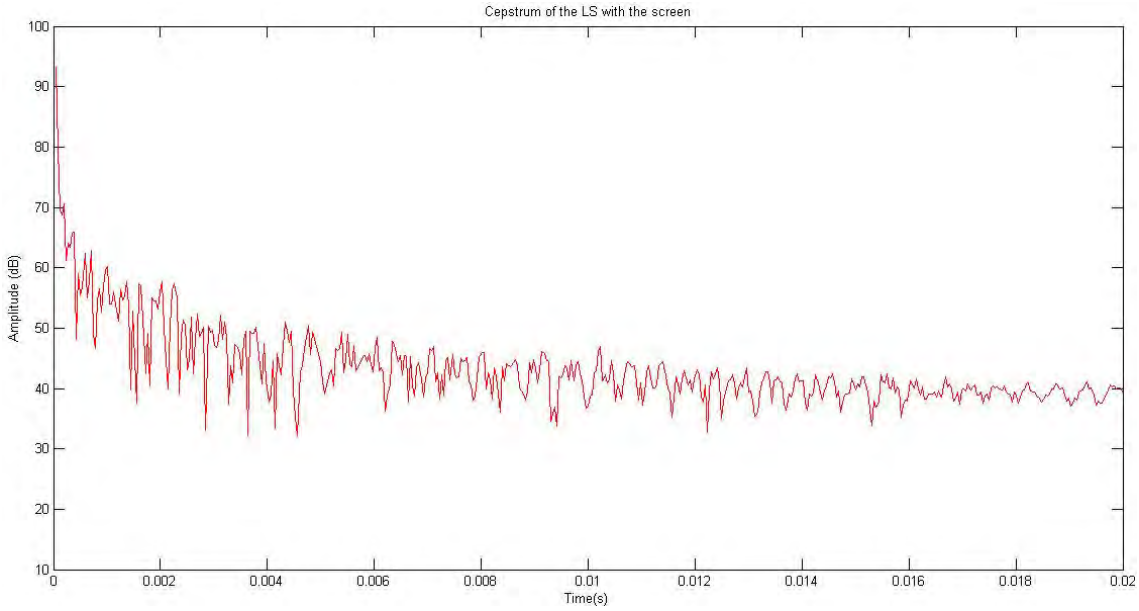

Fig. C. 91: Cepstrum analysis for ClearPix 2 White 1.0 with screen angled 10 degrees. Mic position 30 deg

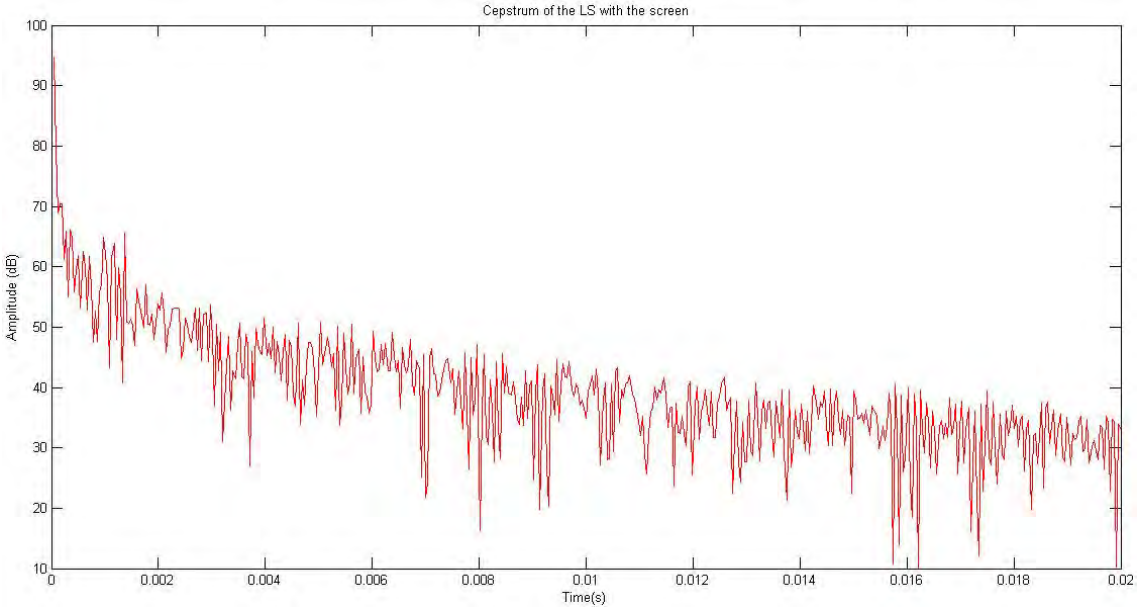

Fig. C. 92: Cepstrum analysis for ClearPix 2 White 1.0 with screen angled 10 degrees. Mic position 45 deg

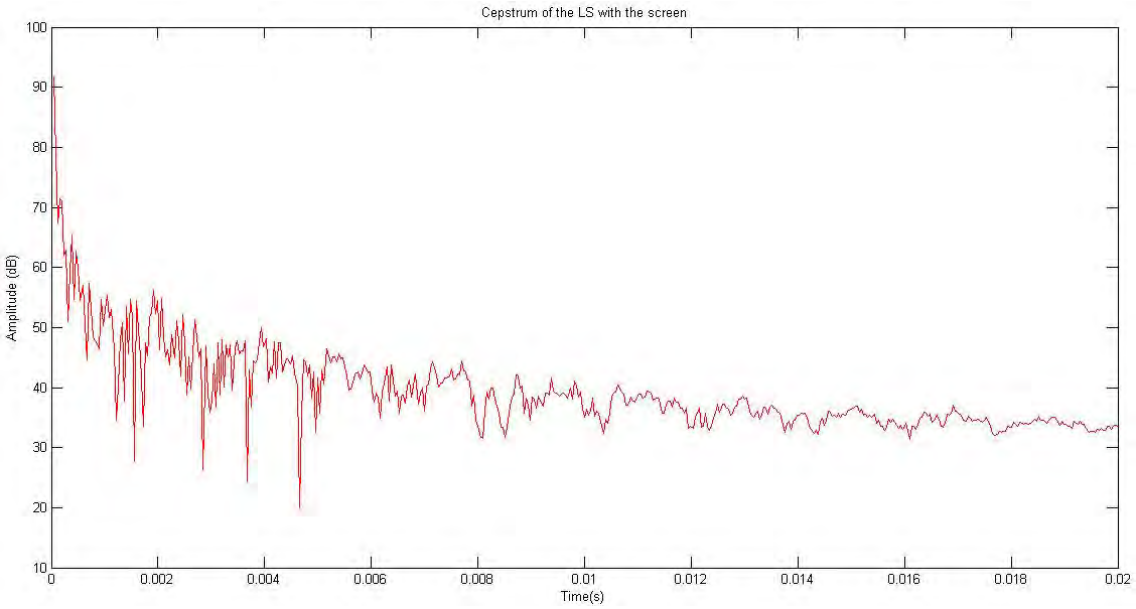

Fig. C. 93: Cepstrum analysis for ClearPix 2 White 1.0 with screen angled 25 degrees. Mic position 0 deg

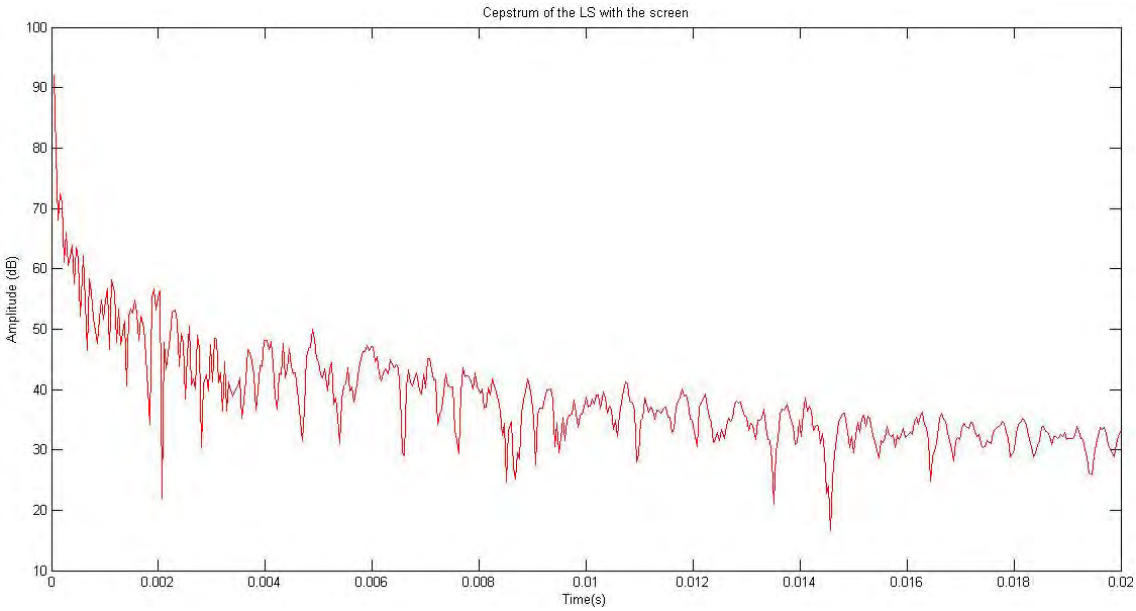

Fig. C. 94: Cepstrum analysis for ClearPix 2 White 1.0 with screen angled 25 degrees. Mic position 15 deg

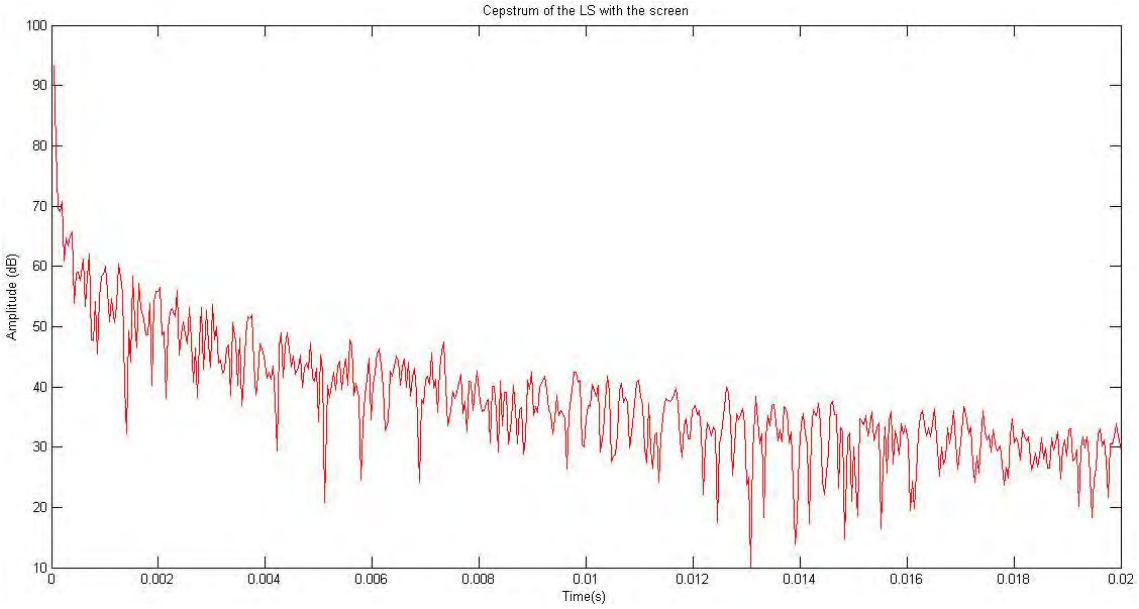

Fig. C. 95: Cepstrum analysis for ClearPix 2 White 1.0 with screen angled 25 degrees. Mic position 30 deg

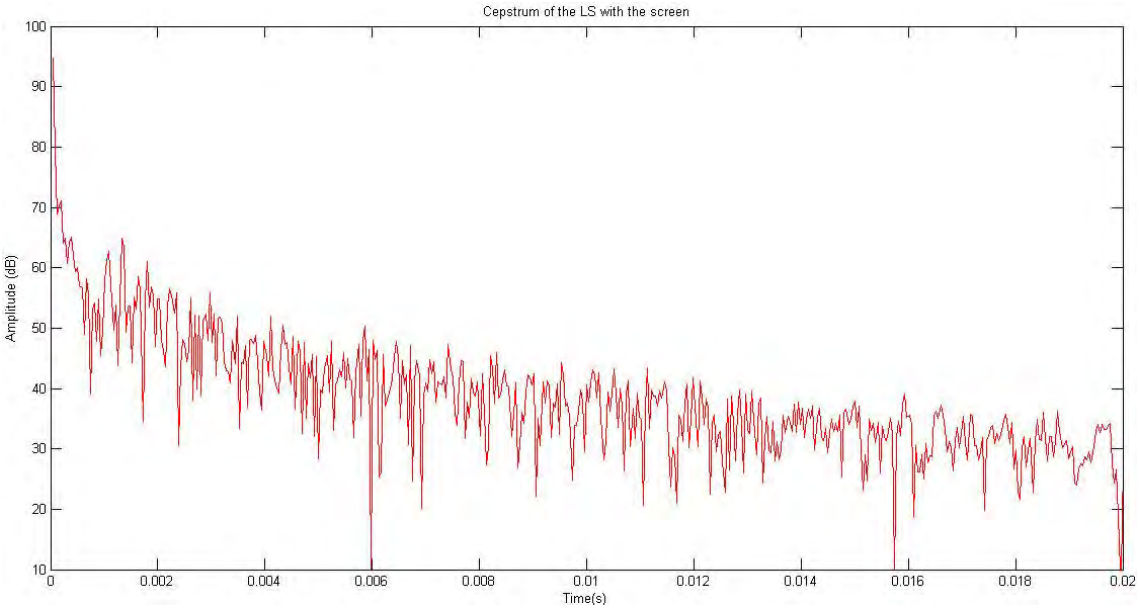

Fig. C. 96: Cepstrum analysis for ClearPix 2 White 1.0 with screen angled 25 degrees. Mic position 45 deg